NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

THESIS

A SYSTEMS ENGINEERING STUDY OF GLOBAL POSITIONING SYSTEM INSTALLATION ONTO ARMY AIRCRAFT

by

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December, 1995

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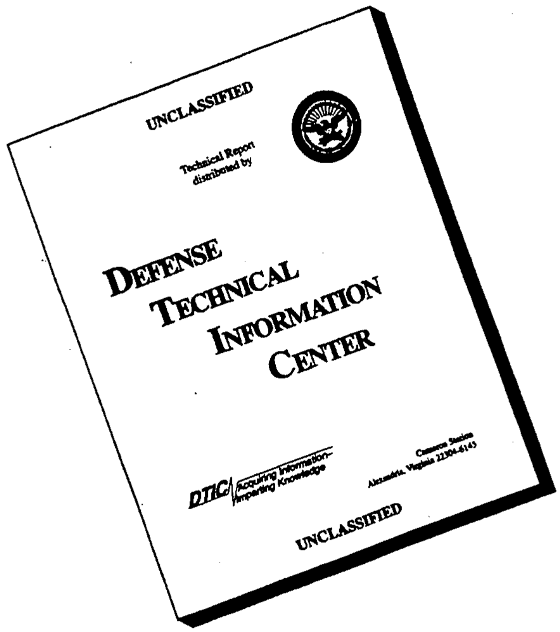

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE December 1995	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE A SYSTEMS ENGINEERING STUDY OF GLOBAL POSITIONING SYSTEM INSTALLATION ONTO ARMY AIRCRAFT.

5. FUNDING NUMBERS

6. AUTHOR(S) Edward D. Grekoski

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)* **The purpose of this thesis is to evaluate the systems engineering effort by the Aviation Research and Development Activity (AVRADA), the Airborne Engineering Research Activity (AERA), and support contractor DOSS to install the Trimble Global Positioning System (GPS) receiver onto Army helicopter platforms. This study is an example of a successful systems engineering effort to install a non-developmental item (NDI) onto existing aircraft platforms in response to an urgent requirement created by the deployment of aircraft for Operation Desert Shield.**

14. SUBJECT TERMS Systems Engineering, Global Positioning System

15. NUMBER OF PAGES 107

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

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A SYSTEMS ENGINEERING STUDY OF GLOBAL POSITIONING SYSTEM INSTALLATION ONTO ARMY AIRCRAFT

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1995

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ABSTRACT

The purpose of this thesis is to evaluate the systems engineering effort by the Aviation Research and Development Activity (AVRADA), the Airborne Engineering Research Activity (AERA), and support contractor DOSS to install the Trimble Global Positioning System (GPS) receiver onto Army helicopter platforms. This study is an example of a successful systems engineering effort to install a non-developmental item (NDI) onto existing aircraft platforms in response to an urgent requirement created by the deployment of aircraft for Operation Desert Shield.

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I. INTRODUCTION

A. GENERAL INFORMATION

The purpose of this chapter is to prepare the reader for the purpose and goals of this endeavor. This chapter will help orient the reader to assist in understanding the focus of this effort, why the subject is important, and what activities contributed information.

B. AREA OF RESEARCH

The topic for this thesis is "A Systems Engineering Study of Global Positioning System Installation onto Army Aircraft". The area of research will cover the issues that must be addressed when installing a non-developmental item (NDI) on an aircraft platform and the Systems Engineering required to produce, and install the system within time, cost, and performance parameters. This report will describe the process of the installation of Global Positioning System (GPS) for Army rotary wing aircraft by the Command and Control Systems Integration Directorate (C2SID) and the Airborne Engineering and Evaluation Support Activity (AEESA). This thesis will be a case study that will tell the story of how the Aviation and Troop Command (ATCOM) quickly fielded GPS for Army aircraft in response to the invasion of Kuwait in August 1990. This study will then analyze the NDI strategy and execution for strengths, weaknesses and lessons learned.

C. RESEARCH QUESTIONS

The primary research question was; " What were the critical issues involved in the installation of GPS on Army aircraft and how were they resolved?". Subsidiary Research Questions were the following:

1. What was the aircraft integration strategy and how was it executed for GPS?

2. What were the principal technical problems associated with installing GPS and how were they resolved?

3. How effective was the management approach?

4. How might the lessons learned from the GPS integration effort benefit future NDI insertions onto existing platforms?

5. What was the history of the effort to install GPS onto Army aircraft in reaction to the Desert Shield/Storm requirement?

D. SCOPE OF THESIS

This thesis will be a case study to identify issues and resolutions involved to install the Non-Developmental Item GPS on Army aircraft. This study is limited to the Trimpack GPS used in Army aircraft and C2SID's systems installation effort. Sources for this thesis are the Command and Control Systems Integration Directorate, Ft. Monmouth, N.J and the Airborne Engineering and Evaluation Support Activity (AEESA), Lakehurst, N.J.

E. METHODOLOGY

The methodology used in this thesis involved personal interviews conducted with Navigation Division personnel at C2SID, and quality assurance personnel at AEESA. Project GPS files at C2SID and AEESA were used in this study as the main reference to identify taskings, actions, and time frames. Desert Shield/Storm after action reports at C2SID were used to assess customer satisfaction. A word search on

Global Positioning System was conducted to add to the information data base. There is no classified material in this thesis.

F. BENEFITS OF STUDY

The study of this systems engineering effort to insert an NDI capability onto currently fielded platforms will identify risks and tradeoffs that can occur. The urgent requirement may lead to a more efficient systems engineering approach than is normally used to meet a need with respect to schedule, cost, and performance. The planning and execution of this acquisition strategy in an urgent environment may be applicable today. The lessons learned may assist in streamlining todays acquisition process in some cases and lead to lower cost and faster fielding of systems. Today's budget constraints may make the development of a capability too expensive and leave NDI the only affordable option. Aircraft platforms are extremely valuable to battlefield commanders and likely to be candidates for future NDI insertions due to the rapid change of rotary-wing technology in the commercial and military markets. The application of Rotary Wing aircraft on the battlefield is a combat multiplier for battlefield commanders. Rotary-Wing aircraft give battlefield commanders the ability to quickly move large numbers of soldiers over long distances day or night. The ability for an aircraft to perform the mission is not unlimited. The aircraft's design limits the aircraft's space, maximum weight, and available power. The pilot is limited by his ability to receive, process and act on information in his given flight environment. The environment the aircraft operates in can be an additional limitation to performance. This thesis will capture the critical issues that must be

This thesis will capture the critical issues that must be resolved to use NDI on aircraft as a solution to a user need. The strengths, weaknesses and lessons learned from Project GPS are critical to aviation material developers. Identifying and understanding the critical issues up front and early on will save time and help material developers make better tradeoffs to reach the optimum solution to install additional systems on aircraft. The strengths, weaknesses and lessons learned from Project GPS are important to aviation materiel developers. Civilian and military aviation related technology will move ahead and it is possible because of budget constraints or wartime deployments that NDI will be the only feasible solution to meet a critical user need. This thesis will be a single source reference for the systems engineering effort that took place to install GPS on Army aircraft.

G. ORGANIZATION OF THE STUDY

Chapter II will give a brief overview of the requirement, organizations involved, GPS technology used, and systems engineering to establish understanding of key areas. Chapter III will describe the planning and execution of the integration effort while Chapter IV will analyze the strengths and weaknesses of this effort from a systems engineering perspective. Chapter V will present conclusions regarding the NDI integration strategy and its execution along with recommendations to improve NDI integration efforts in the future.

II. BACKGROUND

A. PURPOSE

This chapter will explain the events that created an immediate requirement for GPS capability on Army rotary wing aircraft. The technology behind GPS and the limitations of the Army rotary wing aircraft navigational capability is discussed. An overview of the organizations that reacted to meet the challenge of installing GPS on all Army aircraft will be presented. Systems engineering and its relevance to project management and urgent acquisitions is explained.

B. THE REQUIREMENT

In August 1990 Saddam Hussein's Iraqi Army invaded the nation of Kuwait and initiated the Gulf War. The 82nd Airborne Division was immediately deployed to Saudi Arabia, to be followed by the 18th Airborne Corps, III Corps, VII Corps, reserve units and coalition forces. President George Bush had drawn a "line in the sand" by initiating operation Desert Shield. This operation ensured that any further expansionist goals the Iraqi's had would not be realized and the coalition forces would have time to increase forces to successfully mount a counter attack that would liberate Kuwait. The environment the U.S. deployed forces faced in the desert of Saudi Arabia was very different than that in the Continental United States (CONUS). Helicopter pilots had difficulty in determining precise aircraft position. The land was flat and undifferentiable. There were few landmarks that could be used to determine position. Sand dunes would make up the contour of the land but would be constantly shifted by the winds. Navigational aids that were common in the United States including VHF omnidirectional range (VOR), nondirectional beaconing (NDB), and Loran were not common throughout Saudi Arabia and Kuwait. There was a need for the crew of any aircraft to know precisely where that aircraft was at all times throughout the area of operations.{Ref 1} The area of operations included not only Saudi Arabia, but additionally Kuwait and Iraq. Missions in which Army helicopters would take part included air assault operations, attack operations, reconnaissance, Joint Air Attack operations, and supply transport. All these missions required position awareness to fly an assigned route to an assigned location at a required time. In August 1990, the best technology currently available to immediately meet this requirement was Global Positioning System.

C. GLOBAL POSITIONING SYSTEM OVERVIEW

The Global Positioning System is a space-based positioning system that can provide the user with precise position and velocity information. The system is used by both civilian and military users (dual use). Standard Positioning Service (SPS) is provided to commercial users and results in accuracies within 76 meters 50% of the time. The military and selective allies use Precise Positioning Service (PPS) that utilizes selective algorithms to give the military user greater accuracy, selective availability and anti-spoofing. The level of three dimensional position accuracy is within 16 meters for the authorized military users. {Ref 2} The signal transmitted by the satellites consists of two RF frequencies: L1 at 1575.42 MHZ and L2 at 1227.6 MHZ. The Clear Access(C/A) code is readily acquired by all GPS users and is a short code with less accuracy than the P-code. The C/A code is a Pseudo Random Noise (PRN) signal pattern that repeats every millisecond. This is a rate much slower than the P-code rate and easier for receivers to lock on to. The P-code operates at 10.23 BPS and is long and difficult to acquire. The P-Code signal is a seven day long phase segment that has a complete phase cycle of 267 days and used for PPS. The Receiver of P-code is utilizing the PPS by first acquiring C/A code for initial code match and lock on. Next transfer to P-code is facilitated by an algorithm that phase shifts the receiver generated P-code to synchronize with the incoming point of the satellite generated P-code.{Ref 3}

The GPS system is made up of three parts: the user; the space segment made up of the constellation of satellites orbiting the earth; the control segment that is run by the Air Force from Colorado Springs , Colorado with monitoring stations in Hawaii, Kwajalein, Ascesion, and Diego Garcia. The Control Segment directs satellite behavior to include orbit, transmission, power, and receiver availability . The receiver portion is the unit the commercial or military user operates to access position information on the ground from the satellite transmitters. {Ref 3}

Trimble Navigation's Trimpack tracks up to eight satellites simultaneously that are referenced to determine precise position information. Position initialization is not required. The Trimpack uses the best four satellites that it can see for position determination. The system continuously tracks eight satellites, if available, and will always use the best four, as satellite positions change, to determine the best estimate of position. The Trimpack's memory is loaded to have an almanac that gives the orbits of all the satellites currently available at the time of loading. The Trimpack has satellite ephemeris that provides accurate satellite position information at all times. This information is held in battery packed random access memory (RAM) and is updated hourly. When the Trimpack receiver is turned on it uses its memory of the last position and the known satellite orbits from the almanac to find the satellites the receiver believes to be above the horizon and then updates the receiver's new position. Each satellite generates its own Pseudo Random Noise (PRN) code that the receiver uses to positively identify satellites and differentiate one satellite from another. The amount of time required for first time fix after a receiver is turned on is as low as 1.5 minutes for brief power off periods and as high as 15 minutes for long power off periods where the satellite constellation has changed drastically. If a satellite signal is interrupted for more than 15 seconds, a frequency search is initiated to find the signal. The receiver may use almanac, ephemeris, and Doppler information to relock on the satellite or to provide estimates of the new projected satellite position that is utilized by the system to estimate the user's position. {Ref 4}

D. ATCOM OVERVIEW

The U.S. Army Aviation and Troop Command (ATCOM) was the U.S. Army Aviation Systems Command (AVSCOM) located in St. Louis, MO, with a mission to develop sophisticated systems for use in Army Aviation and provide material management support for fielded systems. {Refs 5,11} This command is a major subordinate to the U.S. Army Materiel Command, Alexandria, VA, and has its own subordinate commands and elements at different locations throughout the United States and overseas. ATCOM leverages technologies at their various Research, Development and Engineering Centers (RDEC) for use in future aircraft designs. Examples of technology research that occurs are rotor craft aeromechanics, and advanced cockpit development for man-machine interface. Managing Army Aircraft systems through the entire system life cycle to include research and development, production, spare parts and material support, maintenance and retirement, is conducted by ATCOM. The AH-1 Cobra, UH-1 Huey, OH-58 A/C Kiowa, and C-23 Sherpa, are examples of aviation programs managed by ATCOM. The Program Executive Officer (PEO) Aviation is separate from but collocated with ATCOM in St. Louis. PEO Aviation manages some aircraft systems under development or production to include the RAH-66 Comanche, AH-64A Apache, and UH-60 Blackhawk. ATCOM does support and sustain PEO Aviation aircraft and when the program reaches production maturity the aircraft programs are transferred to ATCOM for long term sustainment. {Ref 5,11}

E. C2SID OVERVIEW

The Command Control and Systems Integration Directorate (C2SID) was the Avionics Research and Development Activity (AVRADA) and is located at Fort Monmouth N.J, with a office collocated with NASA at the Langley Research Center in Hampton, VA. {Ref 5,11} C2SID's mission tasks include a wide variety of roles ranging from research and development to production and support of aviation equipment. Technology issues within C2SID's domain included Aviation Electronics Systems Integration, Avionics Software Development and Support, Aviation Command Control and Communications, and Navigation. Integrating Avionics into aircraft cockpits was a niche for AVRADA. This organization was called upon to integrate numerous navigation, communication, and survival technologies onto aircraft platforms to enable aviators to navigate, communicate, and survive in current and future threat environments. Aircraft Single Channel Ground Air

Radio System (SINCGARS), the Digital Map Generator, the AN/PRC-112 Survival Radio, Integrated Communications, Navigation, and Identification Avionics (ICNIA), are examples of some of C2SID's efforts.

C2SID's facilities include the Audio Acoustic Facility which reproduces the noise environment that aircraft operate in to assess the speech intelligibility of communication systems, and also to evaluate effectiveness of noise attenuation equipment. The Aviation Command and Control Ground Station simulates and provides command and control necessary to properly evaluate aircraft systems or subsystems in a tactical scenario. The Navigation Mobile Laboratory provides the capability to test navigational equipment prior to flight tests and actual performance for some ground and air flight tasks. AVRADA was one of the research and development activities under AVSCOM, but today C2SID is a directorate of the Communications and Electronics Command (CECOM) RDEC.(Ref 5,11)

F. AEESA OVERVIEW

The Airborne Engineering Evaluation Support Activity (AEESA) was the Airborne Engineering and Research Activity (AERA) and is located at Lakehurst N.J. {Ref 1} It is commanded by an Army Lieutenant Colonel and made up of Government and contractor personnel who provide support to DOD customers. There is also a flight detachment located at Davison Army Airfield to support the Night Vision and Electronic Sensors Directorate, Ft. Belvoir, VA. AEESA provides aircraft, pilot support, aircraft maintenance, installation kit production, and aircraft modification support to customers. Aircraft at this activity have changed with time but today consist of UH-60 Blackhawk, AH-64 Apache, AH-1 Cobra, UH-1 Huey, RC-12 Guardrail, C-23

Sherpa and the YEH-60 System Testbed for Avionics Research (STAR). Normally other aircraft required for modification or testing are provided by the customer or the ATCOM. This activity works out of a dirigible hangar with a tarmac adjacent to it and with Lakehurst Naval Air Station runway and control tower facilities.

Contract Support is on-site and provides aircraft maintenance support at the Aviation Unit Maintenance (AVUM), Aviation Intermediate Maintenance (AVIM) levels and some Depot level repairs. They have the capability to produce level II specifications and have modern Computer Aided Design (CAD) equipment. Many customers come to this activity to evaluate their system on one of AEESA's aircraft. The contractor's capabilities include designing and fabricating kits required to install customer systems onto rotary-wing or fixed-wing aircraft. They also produce the installation kit and required aircraft modifications that must be performed for the new system installation. A Government Contracting Officer's Representative (COR) is on-site and overseas contractor performance to ensure quality, efficiency, and safety. Government Quality Assurance Representatives (QARs) assist by inspecting all installations, modifications, and repairs executed by the contractor personnel. Aircraft modification and non-standard installation design must be approved by ATCOM prior to that aircraft being released for flight. The QARs coordinate with ATCOM and send out documentation required to be evaluated. ATCOM makes the final approval or disapproval decision. Approvals are faxed to AEESA before any flight can take place. Supply facilities are on-site and consist of both contractor and Government support. Class IX supplies are ordered by the contractor to support customer projects. High priority and high dollar requisitions are reviewed and approved by the COR prior to execution. All other classes of supplies are requisitioned by Government supply personnel. This unit pays for all parts to include Depot Level Repairables (DLR), and receives credit for DLRs turned in. Fixed and variable costs are assessed by Government personnel and customers are charged a fixed hourly rate. Time spent on customer projects by both contractor and Government personnel are captured on time cards by project code that are input into a computer weekly. Prior to initiation of customer support the customer sends funds via a Military Interdepartmental Purchase Request (MIPR). A Government Project Support Representative initiates a new project account and coordinates project status information to customers. The customer receives monthly statements from AEESA that show the project balance at the beginning of the billing period, what funds were spent for labor, materials, travel, flight support during the period, and the new balance.

Flight Operations provide the resources and work areas pilots need to conduct mission planning to include, gathering current and future weather information, conduct flight planning, and evaluate aircraft performance capabilities and limitations. The pilots at this activity have thousands of hours of flight experience and are qualified to fly numerous rotary wing and some fixed wing aircraft. An Instructor pilot is responsible for pilot training to ensure pilots maintain proficiency in the aircraft they fly for all flight maneuvers required by the Aircrew Training Manual (ATM) and mission unique tasks that are demanded by the unit's mission. A unit Safety Officer oversees safety training and ensures that all activities performed by unit personnel are conducted by the book.

AEESA's combination of civilian, military, and contractor personnel with the aid of facilities and equipment on-site provide one stop shopping to customers.

External engineering support is coordinated and obtained from the parent organization: C2SID. {Ref 1}

G. SYSTEMS ENGINEERING

Systems engineering is defined by MIL-STD-499A as follows;

> Systems engineering is the application of scientific and engineering efforts to (a) transform an operational need into a description of system performance parameters and a systems configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (b) integrate related technical parameters and ensure capability of all physical, functional and program interfaces in a manner that optimizes the total system definition and design; (c) integrate reliability, maintainability, safety, survivability, human and other factors into the total engineering effort to meet cost, schedule, and technical performance objectives.

Objectives of systems engineering include ensuring that the system design captures all critical requirements for all system elements and that technical efforts are integrated to produce an optimally balanced design.{Ref 8} Systems engineering ensures a project is completed on time and meets all life cycle requirements. It defines the requirement on an iterative basis so the final product meets users needs. All user needs are considered and tradeoffs are made to optimize processes involved in the acquisition so the resulting system is producible in a timely manner, affordable, and meets the minimum user need. Systems engineering implements controls and documentation that capture cost, schedule, performance, and risk information that is provided to the decision maker. Timely information is critical for decision makers to have prior to their decisions to commit resources or lock in a coarse of action. {Ref 7} Urgent acquisitions require an optimal systems engineering approach with respect to schedule and performance. Critical activities must be identified, scheduled, and resourced for the quickest execution possible. The acquisition strategy chosen must correctly assess risk to schedule and performance and field a system that meets minimum users needs. A project manager is not the expert in all the required activities that must occur and must lead his people in a team environment and manage critical activities to achieve success.

H. SUMMARY

This chapter has briefly summarized key background information on activities involved in the effort to install GPS onto Army aircraft in response to the Desert Shield/Storm requirement. The technology required to allow GPS to function has been described along with the systems engineering approach to program management. Chapter III will give the history of the GPS installation effort.

III. PROJECT GLOBAL POSITIONING SYSTEM STORY

A. PURPOSE

The execution of the NDI acquisition strategy chosen will be discussed in detail. This chapter will describe the sequence of events and interactions that occurred to create a way to install GPS on Army aircraft in response to Desert Shield requirements. Requirements analysis and problem solving of both anticipated and unanticipated problems will be discussed. We will look at the process, people, and systems engineering that resulted in successful, timely project completion. Tradeoffs to meet urgent tight schedule requirements will be looked at from a systems engineering perspective.

B. STRATEGY AND EXECUTION OF AIRCRAFT GPS ACQUISITION

1. The Requirement

Desert Shield began the first week of August 1990 with Iraq's invasion of Kuwait. On 22 August 1990 a meeting was held at AVSCOM to brief MG Williamson on AVRADA support for Desert Shield. MG Williamson directed AVRADA to proceed with engineering of A-Kits for GPS installation on Army aircraft. AVRADA was to develop the installation, training, logistical support concurrently with the engineering effort.{Ref 8}. At this time the Army Central Command (ARCENT) had not initiated a formal requirement for GPS in Army aircraft and there were no bill payers identified to pay for this effort. On 31 August 1990 a coordination meeting was held by AVSCOM with AVRADA. MG Williamson reiterated his support for the developing of installation kits to mount Trimble GPS on the Desert Shield Army aircraft fleet. He directed a message be prepared and sent to MG Frix to validate the requirement and approve the proposal to equip the Army aircraft fleet with the Trimble GPS. Once MG Frix responded a message was sent to the Deputy Chief of Staff for Operations (DCSOPS) for allocation guidance. Contract support at AERA was suspended pending MG Frix's response. MG Williamson asked for an A-kit price breakdown and that the following considerations be considered for the engineering effort.{Ref 9}

A. Ground to Air Interchangability- The Trimble GPS should have the ability to be quickly removed from aircraft and installed on different aircraft or ground vehicles.

B. Batteries- Safe for flight.

C. Location- Pilot input for location selection is essential, plus take into account location of crew storage of non-cockpit items,e.g. Mission Oriented Protective Posture (MOPP) gear, weapon, water.

D. Kit Production- Should be complete not later than (NLT) 30 days from design completion. If AERA cannot meet this requirement AVSCOM should be notified immediately.

E. Long Lead Time Items- AVRADA must develop a work around plan for long lead time items that may bottleneck kit production.

The A-Kits were installation kits with an antenna/preamplifier that would allow the Trimble GPS to be installed on AH-64, AH-1, UH-60, OH-58, CH-47, and UH-1 aircraft as an additional system.{Apps. A,B,C}

AVRADA sent a message to Program Executive Officer (PEO) Aviation requesting funding for the GPS integration effort. Deputy PEO Aviation COL Holcomb directed $225,000 from the P7M Maintenance account be given to AVRADA to support the effort.{REF 9} This funding was anticipated to last through 30 September 1990 and cover the engineering efforts required during this time frame, but not production.

The Statement of Work (SOW) developed by AVRADA called for developing prototype A-Kits for the following aircraft: AH-64, AH-1E/F, UH-60A/L, UH-60(Medevac), OH-58A/C/D, CH-47D, and UH-1H/V. This system was not to be integrated into the aircraft flight controls. A location for the receiver and antenna would need to be determined and all brackets needed for installation would have to be fabricated. The system would have to function off aircraft power (28VDC). Ground testing, EMC testing, operational flight test, loads and stress analysis, and electrical load analysis would need to be completed and documented for an Air Worthiness Release (AWR) to be given for that aircraft. Level II specifications would be prepared for each type of installation and commercial operator manuals would be reviewed and used if adequate. Installation instructions would be prepared for each airframe the Trimble GPS would be installed on via the A-Kit.

2. Selecting a Course of Action

A GPS installation assessment was conducted between two possible approaches: the Quick Reaction GPS and the Stand Alone. Deputy Chief of Staff Operations (DCSOP's) concern over GPS installation time was the driving force behind this comparison. The Quick Reaction GPS was the current approach and would require from five hrs (AH-64) to 12 hrs (CH-47) to complete the A-Kit installation. Characteristics of this approach include better satellite visibility since an externally mounted antenna was mounted on the aircraft roof at a level so the antenna will be even with the horizon during forward flight to optimize antenna performance. The Trimble GPS receiver is mounted inside the cockpit at a location that best suits the cockpit configuration and pilot needs. This location would also be optimal with respect to outside visibility and other safety requirements. This system would utilize organic aircraft power and not be dependent on receiver battery power to operate. Instant removal is achieved by a slide mount that allows the GPS receiver to be easily removed or installed. {Ref 11}

The Stand Alone installation would mount the Trimble GPS receiver in the glare shield of the aircraft using Velcro to provide the simplest installation possible. Problems resulting from this installation include reduced satellite visibility due to blockages caused by the airframe encountered from the glare shield location and from the tilt of the Trimble built-in antenna to the horizon. A suitable location to mount the GPS using this method on the AH-1 could not be achieved after a field of view analysis was performed by AVRADA/AERA. The Field of View Analysis examined the lateral and vertical field of view the pilot operating the GPS would have with the system mounted to the aircraft glare shield. The study also demonstrates the reduced system availability due to airframe caused signal blockage and not having an external antenna to see the satellites. {Ref 11} Safety was a serious deficiency because of the probability of not being given an Air Worthiness Release (AWR) due to the receiver mounted to the glare shield not meeting crash safety requirements. {Ref 11} If a crash occurred, Velcro would be the only restraint to stop the system from flying off the aircraft glare shield. This was considered a significant safety deficiency by AVSCOM engineers who would give the AWR for the chosen installation design. Sun loading on the glare shield in a desert environment could result in the receiver and batteries encountering temperatures up to 200 degrees Fahrenheit.

Table 1: FIELD OF VIEW/SATELLTE VISIBILITY CHART

	lateral FOV		horiz. FOV		approx. time 3 or more
AIRCRAFT	**left**	**right**	**up**	**down**	**satellites visible (hrs)**
UH-60A/L	**122°**	**122°**	**142°**	**19°**	**16.4**
UH-1V	**120°**	**120°**	**123°**	**13°**	**15.5**
CH47D	**120°**	**120°**	**123°**	**13°**	**14.9**
OH-58C/D	**128°**	**128°**	**132°**	**18°**	**16.1**
AH-64A*	**140°**	**140°**	**122°**	**10°**	**16.4**
AH-1F**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**

\- Only location available in the AH-64A cockpit is behind the gunner's head. Only the pilot can see the unit and neither pilot can operate it at that location.

\- There is no room to mount the system on the glare shield for this aircraft. There is insufficient space above the gunners glare shield and the Heads Up Display (HUD) is at the area above the pilot's glare shield.{Ref 10}

The temperature would have significant impact on the performance and life of the system's lithium battery's. The batteries life expectancy at 193 degrees Fahrenheit is 18 hours. The battery has a thermal fuse that opens at 193 degrees Fahrenheit to prevent explosion. {Ref 10} The fuse would prevent the explosion but not ensure continuous system performance. The shortened battery life due to the high temperatures would create a logistical burden for lithium batteries and more frequent operator maintenance than if the system ran off aircraft power. AVRADA recommended to AVSCOM that the Quick Reaction program continue as described and the Stand Alone program be used in the desert as an interim solution for the requirement. {Ref 11}

3. Impact of Research and Development (R&D) and Contracting

The first aircraft to have the Quick Reaction installation completed was the AH-64 Apache helicopter. {App. D} The engineering effort was complete by November 1990. The speed achieved here was assisted by three events: past R&D for aircraft GPS receiver selection, coordination with Space command (SPACECOM) to acquire GPS receivers, and an already existing Letter Contract for the procurement of GPS receivers. In 1987, Joint Project Office GPS (JPO GPS) funded AVRADA $225,000 to evaluate commercial GPS receivers for use in Army aircraft.{Ref 11} This R&D evaluation effort conducted in 1987 saved time in 1990 because it identified the Trimble GPS receiver as the best choice of six evaluated for the GPS receiver in Army aircraft. This testing also identified GPS reception problems in all rotary-wing aircraft due to the motion of the main rotor blades. The effect of the main rotor on rotary-wing aircraft would cause the gain to jump. Trimble solved this problem by developing computer software to correct for reception problems caused by rotor movement and embedded the chip in the Trimble GPS. {Ref 11} SPACECOM was responsible for controlling the satellites essential for GPS operation. They coordinated with AVRADA launches to increase satellite coverage and loaned them three Trimble GPS receivers to be used for engineering efforts in developing prototype installations. {Ref 11} Finally, the Air Force had an existing letter contract between JPO GPS and Trimble Navigation. {Ref 12} This contract could be modified to support the numbers of receivers needed to equip the aircraft fleet in the desert with the desired GPS capability.{Ref 12}

4. Requirements Definition

AVRADA performed a requirements analysis of AVSCOM and DCSOP guidance to internally generate the requirement for the Quick Reaction GPS program. The requirements analysis took information received during AVSCOM meetings, messages from AVSCOM and DCSOPS, and broke down the perceived ARCENT requirement into smaller pieces so the different elements of AVRADA could start immediately on the Quick Reaction project. ARCENT did not validate the requirement for GPS receivers until December 1990. The ARCENT requirement that came in December was for a navigational capability independent of distance traveled and elapsed time in areas where landmarks are not readily available and the position update capability is critical for combat operations. The AVRADA generated requirement was as follows {Ref 13}:

- Trimpack GPS Receiver- Location should consider pilot accessibility for operation and his ability to directly view the light display. Other considerations included

  - Non-interference with flight controls.
  - Clearance for crew to egress the aircraft.
  - System must be usable with pilot in MOPP IV posture.

- Must not interfere with operator's personal weapon.

- System must not interfere with pilot's ability to see outside the cockpit during flight.

- If possible, location should provide for ease of operation for both pilot and copilot.

- Internal Battery- The system will run off aircraft power but a battery must be kept internally so the system can be removed from the aircraft and immediately be capable of performing its function.

- Remote Antenna- The remote antenna will be hard mounted to the exterior of the aircraft zero degrees horizontal during level flight at a location that will maximize reception from available satellites.

- Power Cable /Brackets- Will be installed in a manner that will ensure for easy installation and maximum performance.

- Air worthiness Documentation- Will be coordinated with AVSCOM Engineering, St. Louis. AVSCOM will send copies of all documentation to AVSCOM for approval of each aircraft modification.

- Testing- Will verify that GPS installation will be adequate to track satellites at different bank angles to allow for normal receiver performance. EMC testing will verify that no flight safety problems occur due to the modification. Test plans and reports will be required for each aircraft modification.

- Installation Instructions- Will be clearly written to adequately describe each aircraft modification. This information will be provided to an on-site AVSCOM representative for the purpose of writing Modification Work Orders (MWOs).

- Engineering Drawings- Level II type commercial drawings will be required for each aircraft modification.

- Technical Manuals- There will be no changes to the current aircraft manuals. A Trimpack operator's manual will be provided for each aircraft modified.

- Kit Fabrication Requirement- Program will ensure that all A-Kits will be produced NLT 30 days from approval of prototype design.

- Integrated Logistics Support- The AVRADA Integrated Logistics Support (ILS) office will coordinate with JPO GPS to prepare an ILS support plan.

- Support Concept- Built in Test Equipment(BITE) will be used to verify proper functioning of the Trimpack receiver. The existing four year warranty will be utilized. Aviation Unit Maintenance (AVUM) maintenance will use BITE to identify defective Trimpack receivers. These receivers will be shipped to Depot and then to the manufacturer for repair and replacement. There will be no Depot Level support planned due the interim nature of the procurement. Spares must be planned for the quantity required.

- Training- CECOM New Equipment Training (NET) Team will tailor the existing Trimpack receiver training plan to meet the airborne requirement.

5. Organization and Planning

Integration efforts for each airframe required to be modified and installed with A-Kits were managed concurrently {App. D} and each effort had an integration effort milestone plan developed based on the perceived urgency that each specific airframe had for GPS capability. Enclosed are examples of two integration effort Milestone plans. {App. E,F} A Quick Reaction Airborne GPS Team was formed (QRAG Team).{App. G} The purpose of this team was to provide a streamlined frame work to facilitate fast problem identification/solutions and result in a quicker fielding for all GPS aircraft installation kits. The normal organizational relationship between division, directorate, and higher headquarters was the following:

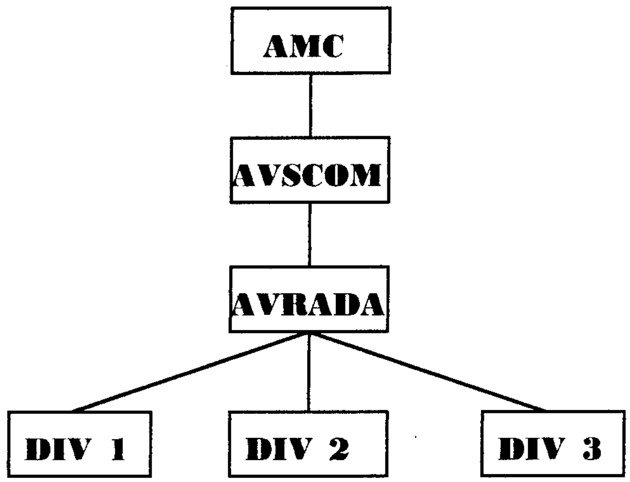


FIGURE 1: TRADITIONAL ORGANIZATIONAL CHART

The relationship between the divisions in AVRADA, the AVRADA director, and higher command AVSCOM was hierarchical. This made for stovepipe communications where information is screened vertically at different levels up and down the organizational chain of command. The implemented streamlined management approach resulted in this organizational structure:

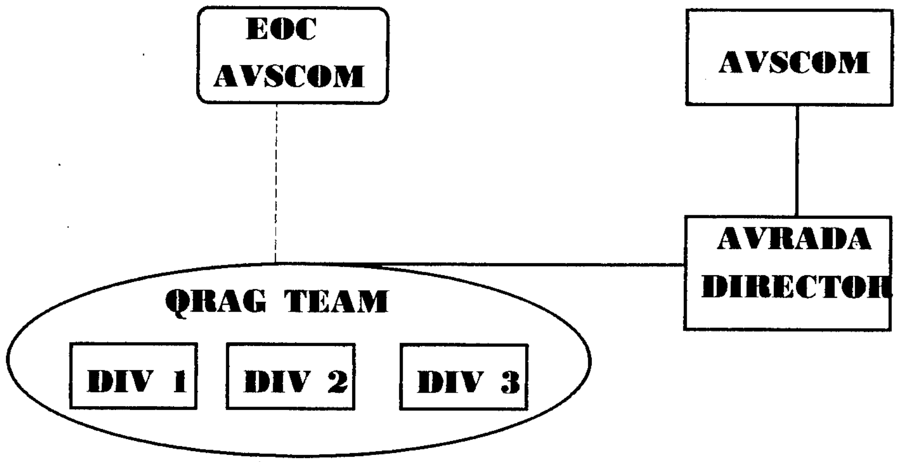


FIGURE 2: QRAG ORGANIZATIONAL CHART

This new organizational communication structures goal was to acheive faster notificaton of requirement changes and quick resolution of project problems. An AVRADA representative was on-site at the Emergency Operations Center (EOC) in AVSCOM and coordinated directly with the QRAG team. {Ref 11} An AVRADA representative at the EOC would receive upgraded requirements from AVSCOM and pass the need directly to the QRAG team. The QRAG team is made up of experts from different divisions of AVRADA. The team was a horizontal integration across divisions of the required skills for project execution into one team The team members were organic to AVRADAs Navigation Division, Installation Division, and Product Assurance Division. Taskings were passed to team members via phone, written taskings, in person, or at QRAG meetings. The AVSCOM director made strategic decisions and would add resources to the existing effort if necessary. The on-site coordination with AVSCOM at the EOC, direct coordination between AVRADA/AERA personnel with AVSCOM engineers for safety issues, and AVSCOM personnel on-site at AVRADA for tech writing are examples of vertical integration of effort between AVSCOM and AVRADA. {Ref 11}

The location of the Trimpack receiver for the Quick Reaction project was determined at AERA by consensus from AVRADA engineers, AERA Quality Assurance Specialists, Contractor personnel(at AERA), AERA pilots, and AVSCOM engineers. Once consensus was achieved on receiver location by considering performance, MANPRINT, and safety, the installation kit was designed and fabricated. This task was performed by the AERA contractor DOSS at Lakehurst, N.J. The contractor fabricated the kits first by taking aircraft measurements and making rough drawings of the installation kit. These drawings would be given to the metal shop for fabrication. The Level II specifications were being created concurrently with the fabrication to save time and it reflected the confidence of the contractor and the Government Quality Assurance personnel in the receiver location decision. {Ref 11}

6. Flight Test

The following flight test description is for evaluation of the Trimpack GPS receiver and external antenna /preamplifier. {Refs 11,14} This installation took place and was evaluated at Lakehurst N.J with AERA pilot's flying the aircraft, AVRADA engineers gathering data, and DOSS contract support to fabricate/install the system and maintain the aircraft. The process will be described for the UH-1 helicopter and was similar for all other airframes {App. H} that required installation/evaluation of the GPS modification to be used by the desert fleet. The process to complete and evaluate the prototype installation with schedule of concurrent activities is shown on {App. E}. The location selected for Trimpack installation on the UH-1 helicopter was on the copilot's side of the center pedestal.{App. D} Antenna/Preamplifier location analysis was conducted by AVRADA engineers to mathematically determine the optimum location for installation with respect to signal reception. The first location chosen for the antenna installation was on the left side of the aircraft's roof (engine hoist hole) on a 12 inch mast so the antenna would rise above the aircraft cowling. Antenna Radiation Pattern tests were conducted at MAT 3, Hangar 5, Naval Air Engineering Center, NAEC, Lakehurst N.J. A UH-1 equipped with the GPS and external antenna would sit on the compass rose facing zero degrees. The Navigation Division van with a signal generator inside and Rockwell FRPA-3 antenna mounted on a four foot diameter ground plane on the van roof would transmit a test signal of 13 dbm on 1575 MHZ. This signal was radiated from the roof of the van 40 feet from aircraft center. The van would move clockwise 15 degrees maintaining the same distance from center and repeat the signal transmission. A spectrum analyzer was connected to the Antenna/Preamplifier to record field strength at each point. The Flight Test consisted of flying the aircraft to known waypoints using Trimpack GPS information obtained in flight. The pilot would then make a series of turns and then fly back to the waypoint. After the second over flight of the waypoint the pilot would hover over the waypoint for a period of time. After the hover the pilot would fly to another waypoint and repeat this procedure. The last waypoint would be completed and then the pilot would fly to a designated return point for a final measurement to be followed by flight termination. During this flight, an AVRADA engineer, would be in the back seat with a Grid computer connected to the Trimpack data port. Data for the entire flight would be collected by the computer and then taken back to AVRADA for analysis. {Ref 11}

Antenna Radiation Pattern tests conducted at Lakehurst show a 21 decibel null {Fig 3} at the 45 degree azimuth caused by the rotor mast on the antenna/preamplifier installation. This was a serious deficiency because nulls of more than 10 decibels at azimuths greater than 30 degrees would seriously impact received signal strength. AVRADA/AERA decided to try mounting the antenna/preamplifier to the back of the wire cutter.{App. A} Antenna Radiation Pattern tests were conducted on the ground as was described for the first antenna installation. Additionally the aircraft main rotor blade was put in the north-south position and then the east-west position. Testing showed that when the blades were in the north-south position there were four nulls ranging from 3 to 7 decibels and when the blades were in the east-west position the nulls ranged from 3 to 14.5 decibels. It was determined the rotor blades would cause a null that would range from 5.5 to 14.5 decibels at 180 degrees. Nulls independent of rotor movement were found at 105, 210, and 330 degrees. In flight collected data were analyzed to determine north and east error, horizontal error at a hover, and altitude and time gaps at waypoints throughout the flight. The data for the first flight(21 November 1990) of the wire cutter mounted antenna resulted in a minimum horizontal error of 24.3meters, a maximum error of 84.2 meters and an arithmetic mean error of 37.6 meters. This error was higher than expected and was explained by the fact that only four satellites were visible during this flight, with several satellites rising and setting. This could have caused a masking effect that would cause poor geometry and make the receiver use old data longer while looking for clearer satellites.Using old data while looking for better satellites would case the larger than expected position error.

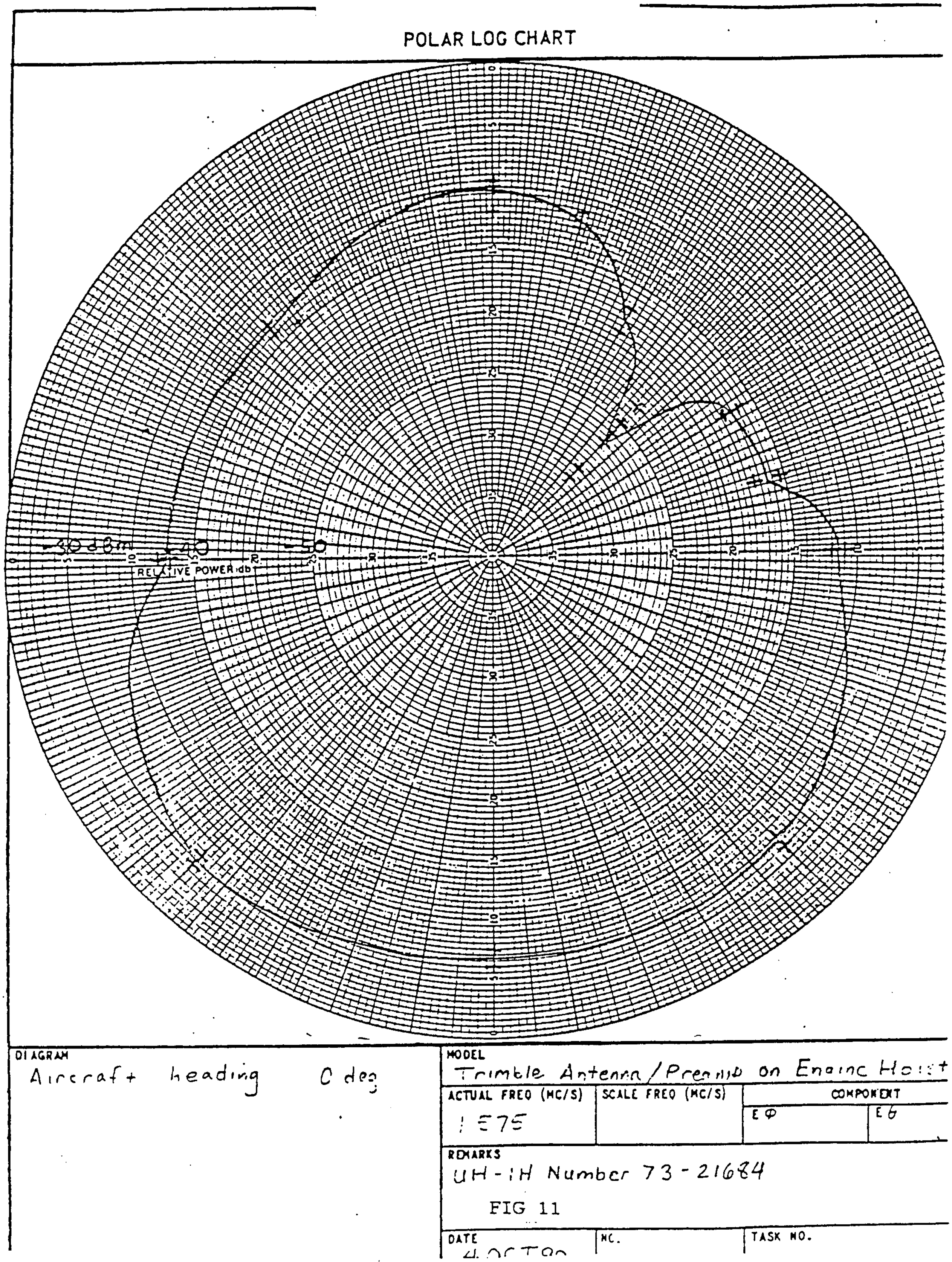


FIGURE 3: UH-1 SIGNAL RECEPTION CHART/ ENGINE HOIST MOUNTED ANTENNA/PREAMPLIFIER

The next flight on 28 November 1990 had a more desirable satellite configuration. The accuracy achieved by the system was excellent compared to the prior flight. The minimum horizontal error in flight was 10 meters, the maximum error was 33.4 meters, and the arithmetic mean was 13.3 meters. During these flights the Trimpack would normally update position every 1-3 seconds with some occurrences of time gaps between 7-15 seconds and a maximum time gap of 45 seconds. The larger time gaps for position updating mostly occurred on the first flight. Pilots were alerted to the fact that position information is old by the Trimpack flashing "OLD" on its visual display. Altitude hold periods where the Trimpack did not update aircraft altitude occurred during both flights. The longer periods were for the first flight ranging from 1 to 3 minutes. Most of the altitude hold periods were far less than this on the second flight and the conclusion was that the satellite problem was caused by masking as in the 21 November 1990 flight. The occurrence of altitude hold would be communicated by the pilot by a flashing "2-D" on the position page of the Trimpack visual display. The better position information on the second flight and the improvement in antenna radiation patterns resulted in selecting the wire cutter antenna/preamplifier installation as the standard for the UH-1 aircraft. EMC tests were conducted on the ground and in flight to evaluate the GPS systems compatibility with other aircraft systems. The evaluation was to check for interference that may be caused by electromagnetic interaction between the GPS system and other aircraft systems because of the close proximity. All electrical systems were turned on and radio checks were made with each type of aircraft radio to check for interference. Navigational aids were also checked in-flight with known points to confirm satisfactory performance with the GPS system operating at the same time. The EMC tests conducted for the UH-1 GPS installation did not find any problems during the ground and in flight evaluations. {Refs 11,13}

7. AERA Support

Concurrently with the flight tests; DOSS was working at completing the Level II specification for the A-Kit showing the wire cutter mounted antenna/preamplifier installation. {Ref 11} DOSS needed to quickly finish the specifications so that the Technical Bulletin(TB) describing the time parts and people required to perform the installation could be written. This information was critical to instruct soldiers in the field the resources and procedures required to install this system onto an aircraft. The TB describing the installation of the A kit was written concurrently as kit production was taking place. Because AERA constantly coordinated with AVSCOM engineers the AWR approval was quick upon submittal of the Level II specification to the AVSCOM engineer responsible for that airframe. The result was that production could occur almost immediately. This process was repeated for each airframe and DOSS expanded production capacity by increasing to two shifts to meet production schedule deadlines. The special machinery required for fabrication of A kits were the bottleneck and more labor during the normal work day would not increase production due to limits in machinery capacity. Long lead time items not normally on hand were ordered at the end of September to support the entire anticipated Quick Reaction program effort. The list was reviewed and approved by a Government Quality Assurance Specialist on site at Lakehurst prior to the contractor submitting the requisition. This on-site coordination and review ensured response and checked the accuracy of quantities and types of materials ordered by the Government.

The contract in place at AERA was a multi-year Time and Materials contract. {Ref 1} The contract was a two-step sealed bid, multi-year contract where the Contracting Officer's Representative (COR) reviewed proposals for technical adequacy with the contracting officer awarding the contract to the low priced technically capable contractor. Small business was given a 10% price advantage over large businesses bidding on the contract. The RFP listed all the job categories and the amount of man-hours the Government anticipated needing. The contractor bid loaded rates that included profit in his proposal. The Government paid the contractor the amount of hours worked in a two week period times the labor category rates the contractor bid in his proposal. The limitation the Government had was that work assigned must stay within the job description of each labor category and the total amount of hours for each category could not be exceeded. The Government could immediately modify the contract to add hours to job categories that would exceed their threshold because of workload. The COR requested the contracting officer modify the contract to add hours to job categories that had greater man-hour requirements than available in the contract. The contracting officer approved and a second shift was started to increase the production of A-Kits. The ability to quickly modifying the contact to increase available labor hours for some job categories by coordination with the contracting officer at CECOM, Ft. Monmouth N.J, provided for an immediate increase in production capacity when required. The Sheet Metal, Electrician, Draftsman, Avionics, Aircraft Mechanic, and Supervisor categories labor hours were increased to support the production and aircraft modification work efforts. The COR changed task priorities in response to changing shipping requirements and project support requirements. The work performed was within the scope of the contract and Government Quality Assurance Specialists conducted inspections on all completed work. The first Shipment of 200 UH-1 A-Kits occurred on 25 January 1991 to be installed on aircraft in Southwest Asia. AERA (DOSS) produced kits for the UH-1H/V, OH-58A, CH-47D, AH-1F, and OH-58D {App. I}. The ability to produce A-kits for all aircraft simultaneously exceeded DOSS capacity so it was coordinated for Corpus Christi Army Depot to manufacture A-Kits for the AH-64 and Tobyhanna Army Depot to produce A-Kits for the UH-60A/L. Tobyhanna also provided for production of small amounts of A-Kits of other aircraft if AEESA could not make schedule. {Ref 1,11}

8. Night Vision Compatibility

Night Vision Goggle compatibility is critical for a system to be useful in aviation night operations. Systems that do not consider this aspect of performance may be useless or even dangerous when operated at night. In December 1990, the QRAG team questioned the Night Vision Goggle (NVG) compatibility of the Trimpack installed on an aircraft glare shield or on the side of a aircraft center pedestal. {Ref 11} Testing was conducted on 10 January 1990 at Night Vision Detachment, Ft. Belvoir, Va. {Ref 16} The results were that the three levels of lighting available on the Trimpack were not acceptable with the system mounted on a glare shield or to the side of acenter pedestal. The ANVIS 6 Night Vision Goggles(AVS-6) are extremely light sensitive. They work off the principle of amplifying ambient light received through two monocular tubes to create a visual display. The pilot and copilot both wear these goggles in flight at night and aircraft lighting is NVG compatible or a filter is put over the light to make it NVG compatible. Cockpit lighting that is greater than acceptable levels can obstruct vision or temporarily shut down goggle operation. The installations evaluated failed in two areas. Trimpacks mounted to the glare shield are in the pilot's field of view. The intensity of the light was greater than normal luminance levels allowed when using NVGs. Normally luminance of .10 foot-lamberts or less is tolerated in a NVG posture. Test results produced luminance levels of .60 foot-lamberts with the Trimpack light intensity in the high position, .29 foot-lamberts in the medium position, and .17 foot-lamberts in the high position.{Ref 15} These results were far outside the tolerable range for safe NVG operations. The Trimpack installed on the side of the center pedestal eliminated the field of view problem but caused the Trimpack display to appear on the wind screen of the aircraft to the pilots wearing NVGs. This image would block real images outside the aircraft from pilot viewing and be a distraction to both pilot and copilot. Next a filter used on SINCGARS displays was placed over the Trimpack display. The results were the display was NVG acceptable at the low light level but not at the medium and high light levels. AVRADA and American Engineering Laboratories (AEL) immediately initiated an effort to modify the Trimpack to correct these problems. An immediate and long term strategy to correct the deficiency in Trimpacks already in the Army inventory in the desert and those coming off the assembly line was needed. It was decided by AVRADA up front that the goal would not be to create a fix that was "ANVIS compliant". ANVIS compliant was defined as the system would meet MIL-85762A allowing the avionics equipment to be installed in any aircraft for use in night operations. The reduced goal was to find a fix that was "ANVIS acceptable" meaning that the specific installation would not cause significant {Ref 16} distraction/degradation to the pilot or copilot when installed in a particular aircraft. On 17 January 1991 AVRADA issued delivery order 022 to contract DAAB07-88-D-H030 for AEL to prototype a filter installation for the Trimble GPS.{Ref 17} The prototype should be evaluated for chromaticity, ANVIS radiance, daylight readability, and light leak. AEL was instructed to coordinate with Trimble Navigation to ensure for mechanical fit and to prepare a cost estimate for 200 kits NLT 1 February 1991, and 2000 kits NLT 31 March 1991. AEL prototyped a NVG filter installation (Fig 4) to be installed by the operator using an Allen wrench to screw on a filter into existing holes in the Trimpack. This approach was used because it could be accomplished quickly without modifying the existing Trimpack. Finding the optimal filter was a more challenging endeavor. On 15 January 1991 a test was performed at Night Vision using a SINCGARS filter with thickness increased from .04 inches thick to .08 inches and with a filter provided by Trimble manufactured by KOPP Glass. Both filters seemed ANVIS acceptable with the KOPP filter slightly superior. {Ref 16} AEL also provided a prototype of a filter embedded into the Trimpack. The prototype consisted of a KOPP filter pressed in between the back of the Trimpack light display and the front of the Light Emitting Diodes (LED). The prototype was tested and found to be ANVIS acceptable and acceptable for day use. Trimble informed AVRADA that they were in the process of designing an embedded filter and the AEL glass filter prototype would not withstand performance in severe environments. Additionally, Trimble was looking at plastic substitutes to reduce the possibility of breakage. On 18 January 1991, a meeting was held with AVRADA and AEL personnel at AEL's plant in Lansdale, PA. {Ref 16} The approach to make already produced Trimpacks NVG

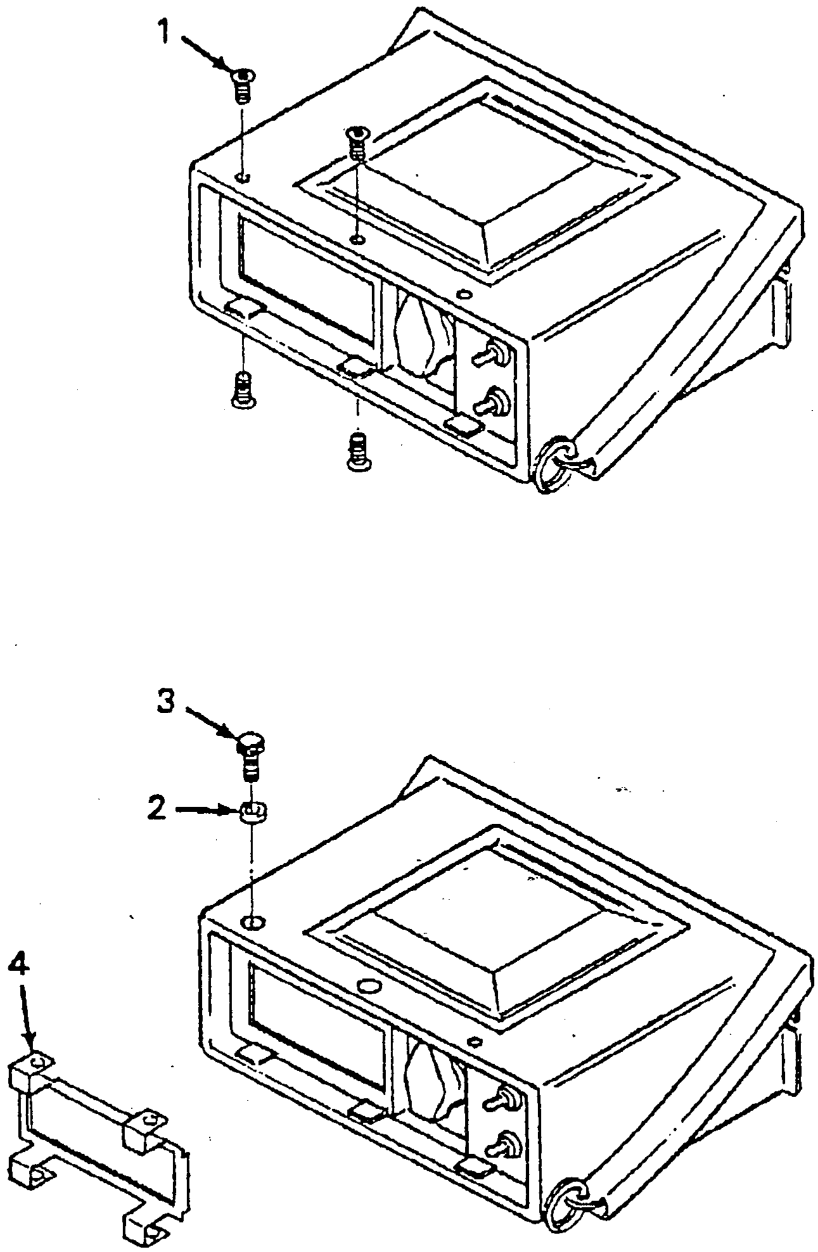


FIGURE 4: ANVIS FILTER INSTALLATION

compatible was discussed and the external filter installed over the Trimpack light display was chosen to solve the immediate problem. The consensus was that the filter installation kit should not require mechanical alterations to the Trimpack, and provide a seal between the filter and the Trimpack display screen. The design used would have to consider the type of filter used and ensure that procurement of the filter could meet tight schedule requirements. On 23 January {Ref 16} AEL provided AVRADA a sample of the filter to be used for the installation kit. This was a modified SINCGARS filter with adjusted thickness to optimize NVG utility. AERA pilots found that there were significant deficiencies with the AEL provided filter. Day flights with the filter installed over the Trimpack light display resulted in limiting contrast between the display and its background when viewed with the pilot's naked eye. Additionally, the display could not be read at all by the pilot when flying with the helmet visor in the down position. This in-flight testing at AERA on 23 January 1991 demonstrated that even though the filter made the Trimpack compatible for NVG flight operations, it would be incompatible for day flight operations. {Ref 16} The filter installation would have to be installed for night flights and removed for day flights. A suggestion was made to change the filter installation to a flip type design where the display would have a hinge on one side and the pilot could flip the filter down against the Trimpack light display for night operations and flip the filter up for day operations. {Ref 11} The mechanical engineering changes would have a significant impact on the filter installation production rate and the consensus between AVRADA and AEL was to stay with the original prototype for the first 200 kits. Canadian Marconi was used as the supplier to AEL because their filter was used during the original tests. {Ref 17}

AEL's task to find a filter supplier to provide a filter that would make the Trimpack NVG compatible yet still suitable for day flights, meet a tight delivery schedule, and control cost was a difficult one. As of 7 February 1991 three filter suppliers were being considered Canadian Marconi, Wamco, and Glar-Ban. The factors used to evaluate the filters was NVG radiance, Photopic Transmission, cost, and ability to deliver quickest. {Ref 17} NVG Radiance measured the brightness of the filtered display to ensure it was within the NVG acceptable range. The Photopic Transmission test evaluated the readability of the display during daylight conditions after the filter was placed over the organic Trimpack light display. The improved filter provided by Canadian Marconi was judged to be the superior filter. It had the best radiance figures and reduced photopic transmission by only 10%. {Ref 18} Canadian Marconi also had the most aggressive delivery schedule with the tradeoff of costing the most. The Glar-Ban provided filter had low photopic transmission that could result in the Trimpack display being unreadable by the pilot in low light day conditions such as dawn or dusk. Wamco's filter was suitable for day and night operations, lower cost than Canadian Marconi, but would require two months for first delivery. Canadian Marconi could deliver 120 of the old filters on 15 February, 160 of the new filters on 22 February, 100 more on 22 March, and the balance on 1 April. Glar-Ban was the low cost filter ($42 ea.), Wamco the next lowest ($72 ea.), and Canadian Marconi the high cost producer ($97.40 ea.). Canadian Marconi was chosen as the supplier to provide filters with gasket installed to AEL for use in the filter installation kit. The QRAG team decided the combination of high quality and quick delivery was subjectively judged to overcome the higher cost required in light of the urgency to field the filter installation kits to Trimpacks in the desert. The CECOM contracting officer sent a letter to AEL on 12 February directing procurement of material required to complete 1500 filter installation kits from Canadian Marconi. On 22 February 1991 Canadian Marconi just delivered the new filters and the urgency caused MG Williamson to ask the president of AEL "turn up the burner" to complete the delivery order on the filter installation kits. {Ref 19} The shops at AEL worked the 23rd and 24th installing the filter into the old design kits. The remainder of the 1500 new filters would go on a new Snap-On type filter cover that had a gasket to provide a seal between the filter and the Trimpack light display. This new design filter installation kit was displayed to AVRADA by AEL on 22 February 1991, at the AEL plant in Lansdale, PA. AVRADA gave permission to proceed with production of the new design. The new snap-on design allowed for easier removal of the ANVIS filter from the Trimpack for day operations, compared to having to use an Allen wrench to install or remove the four screws in the old design. Black anodizing of installation parts were required to minimize reflections, prior to shipping and AEL was directed to complete the action or coordinate with AVRADA to have it done at Lakehurst. Delivery of the filter installation kits began in March 91. {Ref 19}

9. Production Summary

The Quick Reaction GPS program resulted in 1,922 A-Kits being produced between January 91 and April 91. {App. I} Operation Desert Storm was supported by shipping 425 UH-1H/V, 100 UH-60A/L/EH-60, and 50 OH-58A A-Kits and 200 ANVIS filter installation Kits. In March 91 an additional 50 OH-58A A-Kits and 217 ANVIS filter installation kits were shipped to Saudi Arabia. In March 91 Operation Provide

Comfort was supported by shipping 65 UH-60A/L, 18 AH-64A, 8 OH-58C, 20 CH-47D A-Kits and 119 ANVIS filter installation kits to units in Germany deploying to the desert. There were 80 UH-1 A-Kits at Defense Distribution Region West that had been previously shipped to the field. The success of the system in Operation Desert Storm and the lack of GPS still existing in much of the Army's rotary-wing fleet brought GPS to the attention of the Council of Colonels(COC) meeting 10 October 91.{Ref 20} The COC decision was to continue to use the Small Lightweight GPS receiver (SLGR), which is the Trimpack receiver mounted on an aircraft via the A-Kit, as the interim GPS receiver for 50% of the Force Package 1 contingency corps aircraft. This requirement resulted in the need to produce 688 total additional A-Kits more than what was available for the UH-1H/V, OH-58A, OH-58D aircraft and 1288 antennas required for the A-Kit installation. {Ref 20} In December 1992, AERA responded to requirements for 10TH Mountain Division aircraft to be GPS capable for Operation Restore Hope. AERA installed A-Kits in 10 OH-58A aircraft at Lakehurst and deployed a team of Government quality assurance and contractor personnel to install the A-Kits on 16 UH-60 Blackhawk aircraft at the Sikorsky plant in Bridgeport, CT.

Additionally, in January 93 AERA deployed a team to install A-Kits on 12 UH-60 aircraft for the 1ST Cavalry, Ft. Hood, TX, prior to their deployment to Kuwait.

TABLE 2: A-KIT PRODUCTION/DELIVERY INFORMATION CHART

AIRCRAFT	#FABRICATED	#SHIPPED ODS	#SHIPPED OPC	#SHIPPED OTHER	#AVAILABLE
UH-IH/V	425	425	0	0	80
UH-60A/L/EH-60	450	100	65	25	260
OH-58A	50	50	0	0	0
OH-58D	17	0	5	0	12
OH-58C	300	0	8	0	292
CH47-D	175	0	20	0	155
AH-1F	140	0	0	0	140
AH-64A	280	0	18	18	244
ANTENNAS	650	0	0	22	628
ANVIS FILTER KITS	1700	417	119	108	1056

#FABRICATED - A-KITS

ODS - Operation Desert Storm

OPC - Operation Provide Comfort

C. CUSTOMER SATISFACTION

Customer satisfaction information was collected by AVRADA from testimonials received from soldiers participating in the war using GPS. {Ref 26} Additional soldier testimonials were received from Trimble. Higher level leadership testimonials were received from the GPS project office. {Ref 26} A GPS performance assessment was presented at the Fourth International Technical Meeting of the Sattellite Division of The Institute Of Navigation on December 12, 1991. {Ref 25}

D. SUMMARY

This chapter has presented key decisions and events that took place in relationship to the installation of GPS onto Army aircraft in response to an urgent requirement. MG Williamson's direction to go forward with the GPS aircraft installation effort, AVRADA's requirement definition, formation of a QRAG Team, and selecting the Quick Reaction GPS strategy were key decisions. Key events include evaluation of commercial GPS receivers in 1987, A-Kit development, flight testing, production, and identifying the GPS night vision compatibility problems. Chapter IV will analyze the decisions made from a systems engineering perspective for strengths and weaknesses. User feedback and feedback from higher leadership will also be evaluated.

IV. ANALYSIS

A. PURPOSE

This chapter will analyze system engineering decisions made and their execution toward completing the GPS installation effort on Army rotary-wing aircraft. The strategy chosen, organizational structure, and problem solving actions will be evaluated. Finally, customer satisfaction will be assessed from after action reports and statements that were captured after Operation Desert Storm.

B. SYSTEM ENGINEERING ANALYSIS

1. Strategic Decision making

MG Williamson's decision to go forward with the development of Trimpack GPS installation kits for Army aircraft without a validated ARCENT requirement or identified bill payers demonstrated good judgment and strong leadership. He directed AVRADA to begin development on 22 August 1990, but a validated ARCENT requirement was not received until December 1990. Project initiation at this later date would have been too late to complete the development and production effort to support the desert fleet. The early strategic decision that was made allowed AVRADA to start work immediately on the effort, but risked not totally capturing the user need in the final design. This risk was low because of the wealth of experience of the QRAG members on the various disciplines that would be integrated to define requirements, design, locate, and fabricate the installation kits. The validated requirement that finally arrived for a navigational capability independent of distance traveled and elapsed time in areas where landmarks are not readily available supported AVSCOM's decision to install GPS on Army aircraft. The strategic decision made up front and early on gave planning time, clear direction and strategic vision to AVRADA of the scope of work needed to be accomplished.

2. QRAG Team

The urgent requirement forced AVRADA to find a way to quickly install GPS onto Army aircraft. AVRADA realized the urgency of the situation and the need to expedite the development and production phases. The formation of the QRAG team was an excellent management decision to facilitate quick communication and problem solving. This approach streamlined the people involved and allowed many development decisions to be made at the QRAG team level. The QRAG team horizontally integrated functional support and vertically integrated input from AVSCOM and the user. The strengths of the QRAG team approach are fast decision making and requirement identification. The on-site representative at AVSCOM gave the QRAG team quick notification of requirement changes. The QRAG team had the ability to make problem solving decisions and to coordinate directly with AVSCOM on safety and requirement issues. The experience of the team members justified this empowerment. Another way of organizing would be to designate a Program Manager to be responsible for the success of the GPS installation effort and rely on matrix support to complete the required development activities. The advantages of this type of approach is that functional areas can each organize their people to meet all program demands for people and other resources in an efficient manner. The disadvantage is the functional supporter works for the functional manager and not for the program manager. The Program Manager must rely on his people skills to get things done rather than authority. The Program Manager can send back his functional support and contract support if he has the funds and the capability exists in the commercial market. The functional manager will prioritize people and resources to meet his priorities that may or may not increase timely support for a given program. Personnel turnover is always a risk if the functional manager decides to move key functional support personnel to a different program and replace them with less experienced personnel.

The QRAG team approach put all critical functional supporters under one leader. This eliminated the risk of a functional manager changing key people or re-prioritizing. The team personnel responded to one person , the team leader. Supporting personnel are not caught in between a Program Manager and functional support manager. The team approach focuses all critical personnel efforts on one program and places the burden of success or failure firmly on the team. The authority to control team personnel placed on the team leader alone resulted in faster communication, decision making, and execution of actions. Placing many experts on one program team may have resulted in slower progress for other programs, but the urgent requirement justified this approach.

The QRAG team approach achieved the streamlined project effort and seamless communication goals that is today being sought by OSD for ACAT I programs. OSD calls for forming Integrated Product Teams (IPTs) to " move away from a pattern of hierarchical decision making to a process where decisions are made across organizational structures by Integrated Program Teams". {Ref 21} The IPTs will be tailored for the project and will plan and resolve issues at the lowest level. Both approaches result in unity of effort and constant appraisal of program status through development and fielding. This higher level of awareness of critical issues help ensure for better strategic decisions faster. The major difference between the IPTs and the QRAG team is that the need for the QRAG team approach was driven by urgency while the need for IPTs is driven by large reductions in DOD's funding of ACAT I programs.

The experience of the personnel involved and the stability of the civilian workforce greatly contributed to the success of this project. The QRAG team members had many years of experience in their respective disciplines at the same technical position. There was only a very small amount of personnel turnover at AVRADA and AERA. The QRAG team members knew each other well and were used to working together. This provided for a foundation of cooperation and understanding of each other's functions, habits, and capabilities. This is in contrast to industry where turnover is more common and the desire to succeed does not always lead to cooperation between experts.

3. Government Resources

The Government's organic capabilities in personnel and equipment were a positive force behind the project's success. The combination of experienced people and Government-owned equipment and facilities set up a "one-stop shopping" situation where the user requirement could be met locally by experienced people who knew each other well and were able to obtain locally the equipment they needed to achieve success. The Navigation Van, Rockwell FPRA-3 antenna, signal generator and spectrum analyzer used in the Antenna Radiation Pattern tests are examples of AVRADA owned equipment. A Materiel-Developer activity can eliminate its organic test capability in favor of relying on outside test activities for test facilities, personnel, and other required resources. This approach would reduce fixed costs but reduce the flexibility of the Materiel-Developer. He would be locked into using a test range for a specified calendar window, after which another activity may be given the range and resources. The Materiel-Developer would have to deploy his system and people to this site and may not have the time to test-fix-test his system in the allocated test window. A test window at test facilities may not be able to adapt schedule even in urgent situations to meet Materiel-Developer needs. The organic test capability in AVRADA and AERA provides flexibility to the developer and "one stop shopping" to the user. AERA's organic resources include Hangar facilities, different types of helicopters, and Government-Furnished Equipment (GFE) on hand that can support projects requiring aircraft modification and non-standard type aircraft installations. Lakehurst and Ft. Monmouth are only approximately 15 miles apart so movement of people and resources could happen quickly if required. There is a habitual relationship between AVRADA and AERA, where AERA supported AVRADA's needs for system installation and testing on aircraft platforms. This type of requirement was common to the QRAG team. Personnel and resources were already tailored to meet this type of requirement. The habitual relationship resulted in a higher level of mission understanding, and unity of effort when the urgent requirement was tasked.

4. Contractor Versus Government Performance

Outsourcing is a common business practice today where a company will contract out for a service or product rather than keeping the work in house. Competitive pressures, economies of scale on the outside, and strategic goals may make this course of action desirable. The Report of the Commission on Roles and Missions of the Armed Forces, May 24, 1995,{Ref 22} believes that the Government should "outsource activities that need not be performed in the government and reengineer activities that must remain in the government to protect the public interest". The report also states, " More than a quarter of a million DOD employees engage in commercial type activities that could be performed by competitively selected private companies".{Ref 22} Industry can provide engineering services, pilots, and special equipment needed for non-standard installations and testing. Industry may also be able to provide these needs at a lower price to the Government. Competition between corporations for a multi-year support contract to develop and integrate systems onto helicopters may result in aggressive proposals and a lower price to the Government. Government owned facilities and equipment can be used to increase competition where normally the high capital costs would impede new competitors from entering the market. Contracting incentives can be used to affect contractor behavior so he will control costs and increase quality of performance.

A weakness of this approach is demonstrated in the area of navigational systems. Navigational systems are used by pilots for position identification, altitude, airspeed, estimated time to arrival and to provide other needed navigation information. Navigational equipment is used by both commercial and military aircraft but the mission environment is not the same. Commercial aviation moves large numbers of people at high altitudes long distances in a non-hostile environment. Military helicopters fly very low, in good and bad weather, in hostile environments. Antenna installation on helicopters is much more difficult to accomplish compared to commercial aircraft because of lack of space for antenna installation and the many other radios and complex electrical systems that may interact and impact on navigation reception. Reliance on contractor support for aircraft system integration would result in the Government losing the institutional knowledge gained by employees in stable job positions for long periods of time. The institutional knowledge gained by a long time contractor may be lost if a later contract is awarded to a different company. Additionally many contractors, or a prime with various subcontractors, would be needed to capture the various engineering, testing, and flight operations performed by the Government at AVRADA and AERA. The addition of more management tiers from prime and subcontractors may weaken communications effectiveness and increase coordination difficulties in achieving unity of effort between Government, prime, and subcontractor personnel for large complex projects. The prime and subcontractors may not want to fully cooperate with each other because even though they are working together on this Government contract, they may be competitors for others. This may lead to the Government receiving less than best efforts from contractor support in meeting Government needs. Ideas that may result in technological breakthroughs may not be shared with the Government if proprietary utilization of the breakthrough will result in greater profit in the commercial market. This is especially possible for navigational systems and GPS. These systems provide utility as navigational aids not only to the military but also for commercial planes, boats, recreational uses, and possibly automobiles in the future. There could be behavior focused on current and future profit which may conflict with Government desired behavior from contractors. A less than optimal design with respect to cost and performance may be recommended to the Government because of the engineering changes that could be later added and logistical support required downstream. Frequently changing project demands may increase the Government workload to administer, modify, and maintain oversight of the various contracts. There would also be disruptions if a newly let contract was awarded to someone other than the incumbent. The GFE inventory required of the thousands of pieces of tooling and special equipment would disrupt operations and burn large amounts of Government and contractor time. A non-incumbent awarded contract may result in large personnel turnover and the loss of critical institutional knowledge unique to installing navigational equipment on aircraft. Finally, contract award can cause a protest that may require a stop work action or re-solicitation that can cause work disruptions, confusion, hard feelings between Government and contractor personnel, and reduce the effectiveness of the organization. The motivation behind Government personnel behavior include job security, patriotism, and a well-earned retirement after many years of dedicated Government service. The motivation here is to share information, work together and all will succeed. The sharing of information openly, trust, endemic of Government service and elimination of hierarchical communication channels for an IPT like communication channel optimized communications among team members. Optimizing communications is essential for development programs to capture critical needs in design early on rather than making costly engineering changes downstream.

5. Requirements Definition

The QRAG team performed successfully in capturing and balancing user performance requirements with operator considerations. The one exception to this statement is not conducting early system evaluation of the Trimpack night vision operation compatibility. The Acquisition Department of Defense Instruction (DODI) 5000.2 describes the five discrete phases an ACAT I program would pass through to ensure a disciplined and efficient execution of procurement strategy. {Ref 23} Phase 0 defines the most promising concepts to meet user requirements. AVRADA already knew that the Trimble GPS was the best GPS system to be installed on Army aircraft because of the commercial GPS receiver evaluations they conducted in 1987 for JPO GPS. This basically fulfilled Phase 0, the concept exploration phase, of the Acquisition Life Cycle where the most promising concept was already identified to best meet the user need. There was no time to conduct studies of other possibilities. The prior GPS down-select decision made from the 1987 test and evaluation effort allowed the program to start at Phase II Demonstration and Validation. AVRADA had a good background for integrating GPS onto aircraft platforms and had already identified and solved reception problems resulting from installing receivers and antennas on rotary wing aircraft. Modification of the already existing contract with the Air Force and Trimble facilitated a quick response to additional GPS needed. The requirements analysis broke down the AVRADA-defined requirements into smaller pieces that would have to be balanced to achieve optimal design. Success in making the trade-offs between these requirements and capturing them in producible designs was a major systems engineering achievement. The compressed development strategy created by the QRAG team and put to calendar schedule provided a disciplined approach that captured general system engineering critical events required for all airframes {App. H} and aircraft unique critical events. {App. E} This published installation development plan put all personnel on the "same sheet of music" and was a good metric to assess progress. Laying out the prototype plan by aircraft up-front and early on allowed planning to begin immediately to ensure critical activities were properly resourced in a timely manner.

6. Concurrency

This approach combined the Demonstration and Validation phase of the Acquisition Life Cycle with the Engineering Manufacturing and Development phase. Concurrency was essential to ensure all critical activities were completed within a tight schedule window. Developing the test plans and drawing package concurrently with the aircraft modification and kit fabrication and installation was a good decision as was developing the Modification Work Order (MWO) concurrently with ground and flight tests. {App E} These decisions maximized concurrency to speed up program completion and shipments of A-Kits to the field. The downside was that if major problems were found later, all drawings, installation instructions, and previously fabricated kits would have to be corrected.

7. Design Selection

Recommending the Quick Reaction design over the Stand Alone design was a strategic decision that was made early on. This decision locked in a technical approach for the QRAG team and was the equivalent of a decision to go into Phase II, Engineering Manufacturing and Development. The advantages of this approach over the Stand Alone approach was enhanced reception and reliability gained with an external antenna/preamplifier mounted to the roof. The Trimpack was out in the desert already and pilots would improvise ways to install the system until the approved

Quick Reaction team developed installation kit arrived. Many pilots "taped it to the dash" {Ref 24} to access the critical navigational information the system could provide. The engineering change to move the external antenna /preamplifier on the UH-1 was a good decision because it resulted in better reception, reliability, and utility to the user. This was due to the reduced signal masking encountered with the antenna/preamplifier mounted to the aircraft upper wire cutter rather than the engines hoist hole{Fig 3}.

Situational awareness gained by coordinating with the GPS ground control segment to obtain information on GPS availability due to satellite visibility was essential for effective evaluation of test data. The satellite constellation at test time had significant impact on GPS accuracy. Knowing this information allowed for AVRADA to make effective antenna/preamplifier installation location decisions. The decision to relocate the antenna /preamplifier to the wire cutter installation may not have been made without awareness gained by soliciting information on constellation location at test time by AVRADA. AVRADA also solicited satellite coverage information for the Desert Storm area of operations to understand the GPS availability that would be realized by the user. This knowledge would be useful to assist in evaluating operator reports of system deficiencies if they occurred. AVRADA's foresight to solicit satellite location information was another success that assisted in achieving a stable prototype installation design and enhanced awareness of system performance.

AERA supported the planned installation kit prototype effort with flexibility to meet AVRADA's needs and the concurrent schedule of events. The aircraft, pilots, skilled labor, quality assurance personnel, and GFE available on-site made for "one stop shopping" in meeting the aircraft modification, installation kit fabrication, and test requirements. This capability allowed for different aircraft to be modified and prepared for flight side-by-side allowing for easy re-direction of labor and sharing of information. The Quality Assurance personnel could go down the line to inspect aircraft work more easily than if the aircraft were dispersed at different locations. The T&M contract made for easy re-direction of work required by verbal notification from the on-site COR to the DOSS supervisor. This style contract seems especially effective for R&D work where exact system requirements definition at the micro level is not clear and there are many changes to daily contractor utilization. This contract allows for easy expansion of labor capacity by modifying the number of hours for desired labor categories yet does not obligate the Government to use all the hours. Pilot input and input from experienced Quality Assurance personnel helped engineers in determining Trimpack location within the cockpit. AERA's large hangar facilities and location by the New Jersey "pine barrens" provided enough equipment and test air space to conduct ground work and flight tests. This activity provided the core physical capabilities required to integrate the various disciplines required to accomplish the Quick Reaction project. The performance by this activity was critical in achieving the quick results demanded by the installation kit prototype and deployment schedules. This activity is also critical to maintaining the capability of the Army to quickly integrate new systems onto aircraft platforms in a timely manner to meet future user requirements.

8. Night Vision Compatibility Problem

The night vision incompatibility of the Trimpack was the greatest problem to be overcome for the QRAG team. This requirement was not identified early on in the AVRADA requirements identification effort. The decision to ship installation kits without this capability utilized a PRE-Planned Product Improvement (P3I) strategy. A system that partially met a requirement was fielded to be followed by a modification to enable the system to fully meet the requirement. In the interim, soldiers in the field would adapt to cover the display at night with an object and lift the object to peek at the display for a short moment to obtain navigation information. The selected snap-on design was superior to the initial filter design which required four screws to be removed and then installed with the filter. The screws were small and could easily be dropped in the aircraft or on the sand in the desert and lost. The snap-on design is simpler for the user to install or remove the filter. This is important because with the NBC threat in the desert the operator may not have the dexterity with his hands to remove and install these small screws. The operator could be in MOPP IV and would be required to wear rubber gloves that would make handling small objects requiring dexterity more difficult. The snap-on design would still allow the operator to install or remove the filter in MOPP IV with little difficulty. The snap-on design was good but the filter design effort did not begin until December. A military aviator with a Level III Acquisition education would have been a valuable member of the QRAG team. He would have an understanding of both tactical realities and the acquisition process. This type of person may have identified the Trimpack night vision compatibility issue early on and may have identified MOPP IV user limitations and champion the snap-on design concept. The time lost between August and October and the difficulty encountered in finding a filter acceptable for day and night operations complicated the problem.

The quick problem solving and development capability gained by having all critical people and assets locally was lost in the filter modification development effort. Filter testing was conducted at Ft. Belvoir to determine night compatibility, Lakehurst N.J for filter day compatibility, and the AEL contractor plant in Lansdale PA for filter installation design.

9. Time Line

The time required to identify and communicate the Government requirement, down-selection of contractors, and production and shipping of kits is as follows; On 10 January 1991 the first filter tests were conducted at Ft. Belvoir and determined the Trimpack display NVG incompatible. On 15 January 1991 a modified SINCGARS filter was tested and deemed ANVIS acceptable. On 7 February 1991 three manufacturer's proposals were being evaluated for filter procurement to be part of AEL's filter installation kit and Canadian Marconi was not contracted until 12 February 1991. The urgency of this period increased with Desert Storm beginning in the middle of January. The time frame identifying the deficiency (10 January 1991), contracting for filters (12 February 1991), with first delivery (22 February 1991) is too long. The better course of action would have been to issue a letter contract to Canadian Marconi on 15 January 1991 when it was demonstrated the snap-on filter was ANVIS acceptable. This action may have moved the delivery date up one month from the 22 February 1991 date. This would have eliminated time lost soliciting for and evaluating offerors. Obtaining a waiver to lock in a supplier sole-source rather than competing out a contract would have allowed the contractor to get started faster. This makes sense in light of the lack of market information on supplier capabilities and the existing urgent requirement. The lack of market information on the capabilities of industry to provide ANVIS compliant filters under short notice was a major unknown. Market survey information needs to be collected to understand the capabilities of industry and must be updated regularly. Market information on materials that facilitate night vision compatibility for commercial navigational equipment is especially important because of its possible use as NDI on tactical aircraft. The utility of NDI is usually obvious but the actions and materials required to adapt the NDI for tactical uses are not always easy to capture. The addition of a military aviator, acquisition education level III, market survey filter information, and an immediate sole-source filter procurement decision would have made a significant positive impact on timely filter installation prototype completion.

C. CUSTOMER SATISFACTION ASSESSMENT

Customer reaction to the Trimble GPS use on Army aircraft to provide precise navigational information was overwhelmingly positive. There was no quantitative survey conducted to support this assessment but after action reports and user testimonials do support this conclusion. {Ref 26} Desert Storm began with Army AH-64 Attack Helicopters destroying two IRAQI early warning radar sites.{Ref 25} Destroying these sites was critical so IRAQI air defenses would not be alerted to future Coalition sorties against them. Two GPS equipped MH-53 Pave Low helicopters from the Air Forces 20th Special Operations Squadron, led four Apache helicopters, from the 101st Air Assault Division, under enemy radar to their initial points (IPs) of attack that were marked with chem-lights. Previous reconnaissance had identified the location of the enemy sites and the locations were programmed onto the Apache's on-board target acquisition and missile firing computers. Exact enemy location information was essential because searching would alert them of the Apaches and the advantage of surprise would be lost. An accurate position update over the chem-lites to the Apache's organic doppler radar allowed for immediate target acquisition and destruction of the targets. A factor that helped General Schwarzkopf approve the mission was the ability of GPS to provide precise location information to the U.S. pilots. {Ref 25} The air assault conducted by the 101st Air Assault Division during the ground war was the largest air assault operation in history. A pilot testimonial {Ref 26} in the lead aircraft complemented the Trimpack's utility in providing extremely accurate position information in marginal weather, both day and night. MG Binford Peay, commander of the 101st Air Assault Division reinforced this perception stating " GPS receivers were the most popular new piece of equipment in the desert" {Ref 24}. Attack helicopter pilots also obtained utility from the Trimpack. An AH-64 Apache company commander stated, "GPS was the savior! It was the most important thing to anyone out there... I taped it to the dashboard and went with it. If you did not have GPS you were screwed." {Ref 24} The decision by the user to keep their Trimpacks rather than turn them in to depot, and the decision by the Council of Colonels to procure 688 additional A-kits for Trimpack installation exude customer satisfaction with the performance of the system and desire to have it installed in all aircraft. AERA's quick reaction to install GPS onto aircraft prior to deploying for Operation Provide Comfort and Operation Restore Hope demonstrate customer satisfaction and desire for more of this capability for use in different operational environments.

Performance and design concerns voiced after the war include testimonials with times where the system did not track three or more satellites.{Ref 26} This may be due to the immature satellite configuration early in the desert deployment prior to the launching of additional satellites. The user requested that in the future GPS be integrated into aircraft flight displays and that it have anti-spoof capability. Additionally, AVRADA re-emphasized the need to develop better battery sources and emphasize early in design minimal power consumption for future systems.{Ref 27}

Customer feedback from personnel at high and low levels acknowledge the success of the Trimpack in providing precise position information that local maps and organic navigational aids could not. The deployment and installation of this NDI system on Army aircraft resulted in greater situational awareness and a significant technological advantage over the enemy.

D. SUMMARY

This chapter analyzed the strategy, organizational approach, key decisions made, and customer satisfaction for the GPS installation effort. Areas analyzed included the formation of the QRAG team, requirements definition, choosing the Quick reaction strategy over the Stand Alone, performing the work in-house rather than contracting out, system installation use of concurrency, the reaction to the night vision compatibility problem, and customer satisfaction. Chapter V will make conclusions and recommendations based on this analysis.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The execution of the Quick Reaction strategy was an example of successful use of systems engineering to install NDI on existing airborne platforms and to meet an urgent requirement. The QRAG team was successful in executing their Quick Reaction strategy because they identified and performed actions critical to systems engineering in an exemplary manner. These actions include performing requirements analysis, capturing critical factors in design, and in integrating efforts by experts from different fields synergistically to support an aggressive schedule. The quick identification of requirements, prototype completion, and A-Kit production is a systems engineering success. Centralized up-front planning, and detailed requirements definition and analysis in an expedient manner allowed more time for execution of critical activities.

A streamlined organizational structure and decentralized execution of key events empowered personnel to quickly execute events, solve problems, and meet schedule. The streamlined QRAG team demonstrates the potential for Government teams to perform more efficiently than industry if empowered by upper level management to work autonomously and make decisions. The institutional knowledge, local availability of resources, and streamlined communications between AVRADA, AEESA, and AVSCOM reduced the time for information to be passed, evaluation of key event results, and decision making.

The QRAG team was empowered by allowing the team to make most decisions organically with only strategic and resourcing decisions made at higher levels. The urgency driven by the war in the desert caused normal stovepipe paradigms for large organizational communications to be broken and replaced by the faster vertically and horizontally integrated QRAG team.{Figs 1,2}

The value of having a long term stable Government work-force for RDT&E is demonstrated in this study. The technical experts achieved synergy without going through the growing pains that groups of unfamiliar personnel go through when thrown together into a team. The synergy was already there from years of habitual support in the area of airframe modification, aircraft system integration, and aircraft system test. Maintaining Government experts locally in engineering, aircraft antenna testing, aircraft structural modifications, aircraft electrical modification, pilots, aircraft avionics, and production and test capabilities, provided an effective personnel mix to complete this systems engineering effort.

Organic physical resources to include flight facilities, shop facilities, and test equipment, available locally are essential for quicker systems engineering and provide one-stop shopping to customers. Having all the critical physical resources on-hand locally makes for easier planning, execution, communication, and integration of key activities. The test capability give a test-fix-test capability locally rather than having to deploy to a test range and being schedule restricted by a tight test window. Installing NDI on aircraft is a valuable niche for AVRADA and AEESA. These organizations provide quick, quality service to customers and are a valuable asset in evaluating potential NDI use on Army aircraft.

Early RDT&E conducted to select the optimal commercial GPS receiver for Army aircraft in 1987 paid off in 1990. The work conducted by AVRADA and funded by JPO GPS revealed the problem of rotor interference on GPS reception. Trimble Navigation solved this problem by developing software on a chip and embedding it within the GPS receiver. The study also identified the Trimble Trimpack as the optimal commercial GPS receiver for use in Army rotary-wing aircraft. The earlier effort to evaluate commercial GPS capability on Army aircraft reduced the technical risk of the 1990 Quick reaction effort by modifying the Trimble receiver to be rotary-wing compatible. The Quick Reaction systems engineering effort was supported by having a rotary-wing compatible GPS receiver at the start of the Quick Reaction project. This saved valuable time and solved the rotor signal interference problem that would have caused the 1990 effort unacceptable schedule delays. The modification to the Trimpack GPS receiver would have been a show-stopper to the Quick Reaction systems engineering effort, and demonstrates the unexpected problems that may be encountered when attempting to solve a mission need with an NDI strategy.

Integrating an NDI capability onto a military platform may seem simple at the beginning of a platform installation or integration effort but later display unforeseen problems. The Quick Reaction strategy essentially installed a NDI GPS receiver (Trimble Trimpack) onto military airborne platforms. Early systems engineering efforts to integrate NDI onto military platforms may identify critical deficiencies early-on as in the GPS RDT&E effort. Early platform installation of NDI will result in identification of operator/system interface issues, performance issues, and platform physical/functional configuration issues. These issues can be addressed with regard to cost risk and performance risk to modify the NDI for compatibility in use on tactical platforms. Government in-house teams with experienced personnel from different disciplines may have the institutional knowledge from past efforts to make better, faster decisions, and reduce cost and performance risk of NDI platform installations. The quick pace of avionics advancement and growth in communications technology in general may make commercial NDI tactical use less obvious to contracting personnel but clearer to technical expert materiel developers. AVRADA's early identification and evaluation of commercial GPS receivers gave a snapshot of industries' GPS capabilities at that point in time.

The T&M contract gave the Government the ability to continually change priorities without undue administrative delays. The contractor was told what to do (not how) and responded immediately. The support role during flight testing pushed the relationship into day-to- day direction as test data revealed new flight requirements and aircraft modification requirements. This day-to-day relationship is necessary to work as a contractor-Government team in aircraft systems installation. This may be a personal services relationship, but Government pilots and engineers, and contractor system installation personnel and flight support personnel have to work extremely closely on complex systems engineering efforts. In aircraft systems integration the original plan may be consistently modified because of unscheduled problems. This was demonstrated when the external antenna/preamplifier had to be relocated on the wire cutter of the UH-1 to improve signal reception. A team that can constantly adapt and improvise is needed to complete this type of project.

Concurrency of critical activities is increased between development and production by having the aircraft, people, and tools needed under the same roof. Breaking out the capabilities to prototype, produce installation kits, and evaluate NDI, to contractors in different geographical locations may result in less efficient communications, and integration of efforts due to distances between efforts. Requirements and key concerns may not be captured early-on in the systems engineering effort if later phase personnel are far away. This was demonstrated by the QRAG team missing the requirement for a night vision filter until later and AEL creating a screw-on design first rather than a snap-on design filter. Having key personnel together at the start of a systems engineering effort can bring out design, production, and support concerns early and avoid the need for Engineering Change Proposals (ECPs) later. Contracted development support and production capabilities vertically integrates Government control of a systems engineering effort from concept identification through development, production, and fielding.

The customer was satisfied by the product of this systems engineering effort. The ultimate measure of the success of this NDI strategy is customer satisfaction. The decision by Aviation units deployed to the desert to keep the Trimpacks in their aircraft combined with positive testimonials from tactical users reflect great credit on the Quick Reaction GPS installation effort. The Council of Colonels decision to procure 688 additional A-Kits for use in Army aircraft and the insistence by units to have the installation completed prior to deployments in support of Operation Provide Comfort and Operation Restore Hope validates customer satisfaction with this new capability.

An NDI strategy using systems engineering disciplines to integrate new commercial technology onto military platforms may be the only affordable strategy to modify our current platforms to maintain performance superiority over future threat systems. The current trend in procurement seems to be system modification rather than new system procurement. The next war may be a "go-as-you-are-war" with no new systems to replace those procured in the eighties due to down-sizing and budget constraints. The proliferation of technology may rapidly enhance capabilities of military platforms anywhere in the world. Commercial technology used by threat forces may reduce our current technological superiority and result in an enemy with tactical capabilities and situational awareness equal to our own. Worldwide proliferation of GPS technology is an example of a commercial capability applicable on the battlefield not widely available in 1990 but easily available today. The Army that most quickly identifies, captures, and incorporates commercial technology onto existing tactical platforms may have a significant performance advantage over their enemy. Small system engineering teams of Government technical experts identifying commercial NDI capabilities and working with industry support in Government facilities to develop optimal platform installations under one roof may be the fastest and most affordable method to achieving an initial operating capability provided by NDI.

A waiver to the CONUS contracting officers to award the filter procurement contract sole-source and without competition should have been given. This would have saved time in completing AEL's night vision filter installation kit and fielded the kit up to one month quicker. Time was the scarcest resource in this effort and evaluating offerors for a competitive buy takes too long in this scenario.

B. RECOMMENDATIONS

The capability to install and integrate systems onto aircraft should not be outsourced to industry. The optimal design of NDI installation kits and assessment of NDI for military use has been demonstrated to be responsive when conducted by the Government in this study. Sub-optimal NDI strategy and execution may occur if NDI systems engineering efforts were controlled by industry. The scope of this effort requires large facilities and personnel of many disciplines. Contracting out this service may result in spreading out the technical disciples geographically to perform these functions at the location the contractor deems best. This systems engineering effort works better when the activities are performed by a team of personnel at local facilities. Breaking out functions geographically will increase the performance risk and schedule risk of the systems integrator as demonstrated by the night vision compatibility problem. Industry complements Government R&D management when used in the support role and in providing a limited production capability. The support provided by DOSS personnel using GFE, facilities, and flexibility inherit in the T&M contract ensured timely development and production support.

An Acquisition Officer with a level III acquisition education should be part of military platform system installation or integration efforts. The late identification of the night vision compatibility deficiency shows the importance of having personnel with a tactical background together with an understanding of systems engineering. An Acquisition Officer with a level III acquisition education would understand the acquisition process and the tactical concerns that are critical to be captured early in a system's design. A person with this background will be a valuable member to any systems engineering effort that involves integrating NDI onto a current tactical platform.

The Government needs a mechanism to identify evolving commercial capabilities and data-base to record the off-the-shelf technology. The information search should look at current and future requirements and technology that can improve existing platforms. Capturing a commercial capability and modifying it to meet a military need without a requirement sounds like gold-plating but if the RDT&E

effort to select the best airborne GPS receiver was not accomplished in 1987; there would not have been time in 1990 to find and install a receiver on all the airframes in the desert fleet. The gold-plating of today may meet the requirement of tomorrow. Recording commercial capabilities and the companies with the capability to provide them in a central data-base will result in a single source that can be referred to when a requirement creates the need to modernize old platforms or build new ones. The data-base must be continuously updated. Market surveys need to be conducted to identify commercial equipment made by the military industry and non-military industry. The Government technical experts are the best choice to conduct market surveys. The market survey may be used as a tool to find NDI that meet a mission need installed on a platform or used as a stand alone system. NDI may also be identified that can inexpensively add value but not respond to a specific requirement. The personnel conducting the market survey should be the same people who have the institutional knowledge to integrate this type of NDI onto military platforms. Understanding the technology is critical to assessing potential NDI military applications and identifying possible platform interface problems.

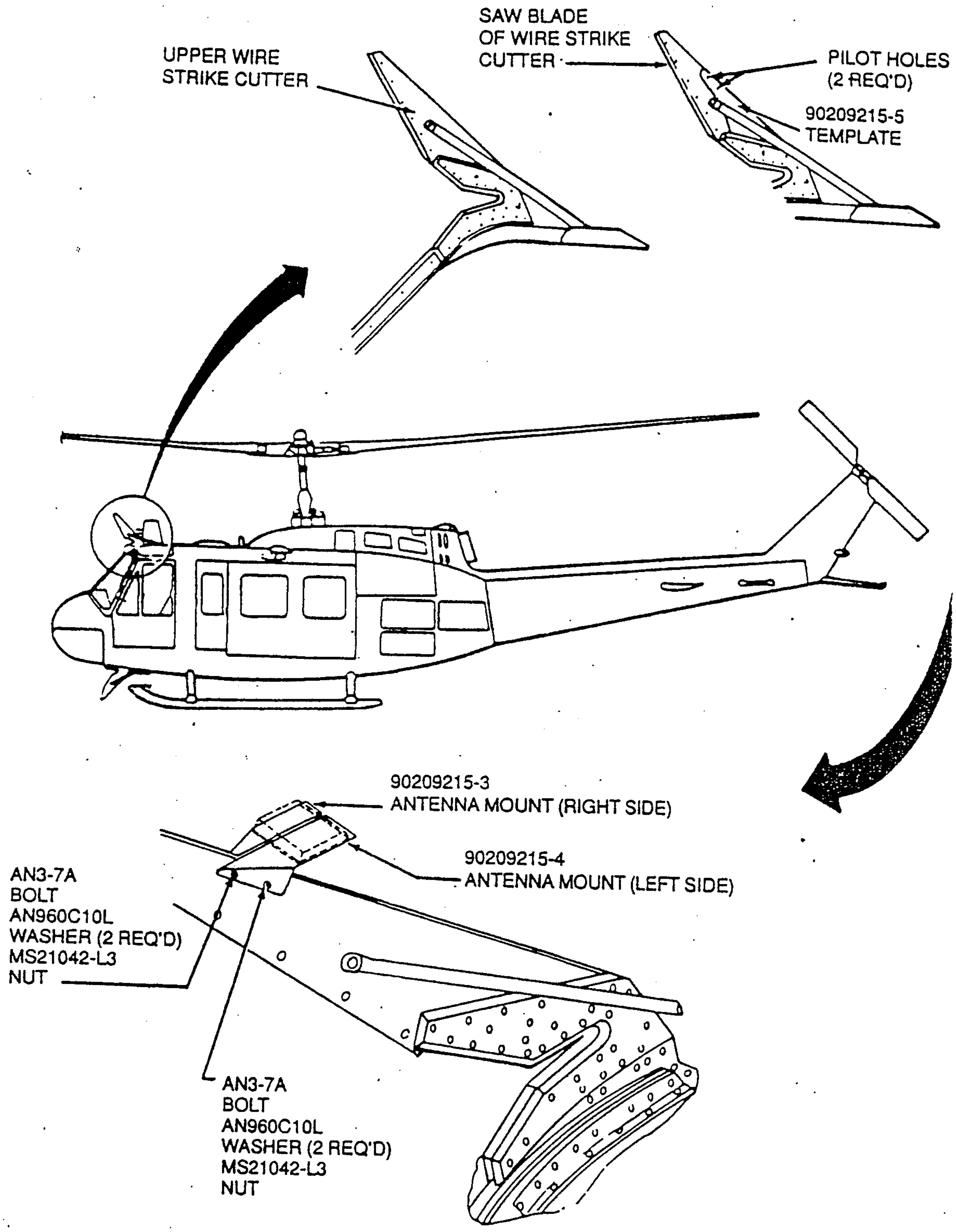
The prohibited personal services relationship between Government and contractor personnel should be waived for systems engineering efforts that require Government and contractor personnel to work as a team. This will remove a unnecessary barrier and add value by increased unity of effort. Day-to-day direction is necessary in complex aircraft system integration efforts that result in constant plan modification to new problems that arise.

Procuring activities need to ensure the mechanism exists to quickly give Contracting Officers a waiver to allow them to award contracts sole-source to meet urgent requirements. Justification and Approvals (J&As) take time to create and get approved. In urgent requirements, time is the most valuable resource and contracting officer actions should not be a show stopper in completing and fielding a system.

C. AREAS FOR FURTHER RESEARCH

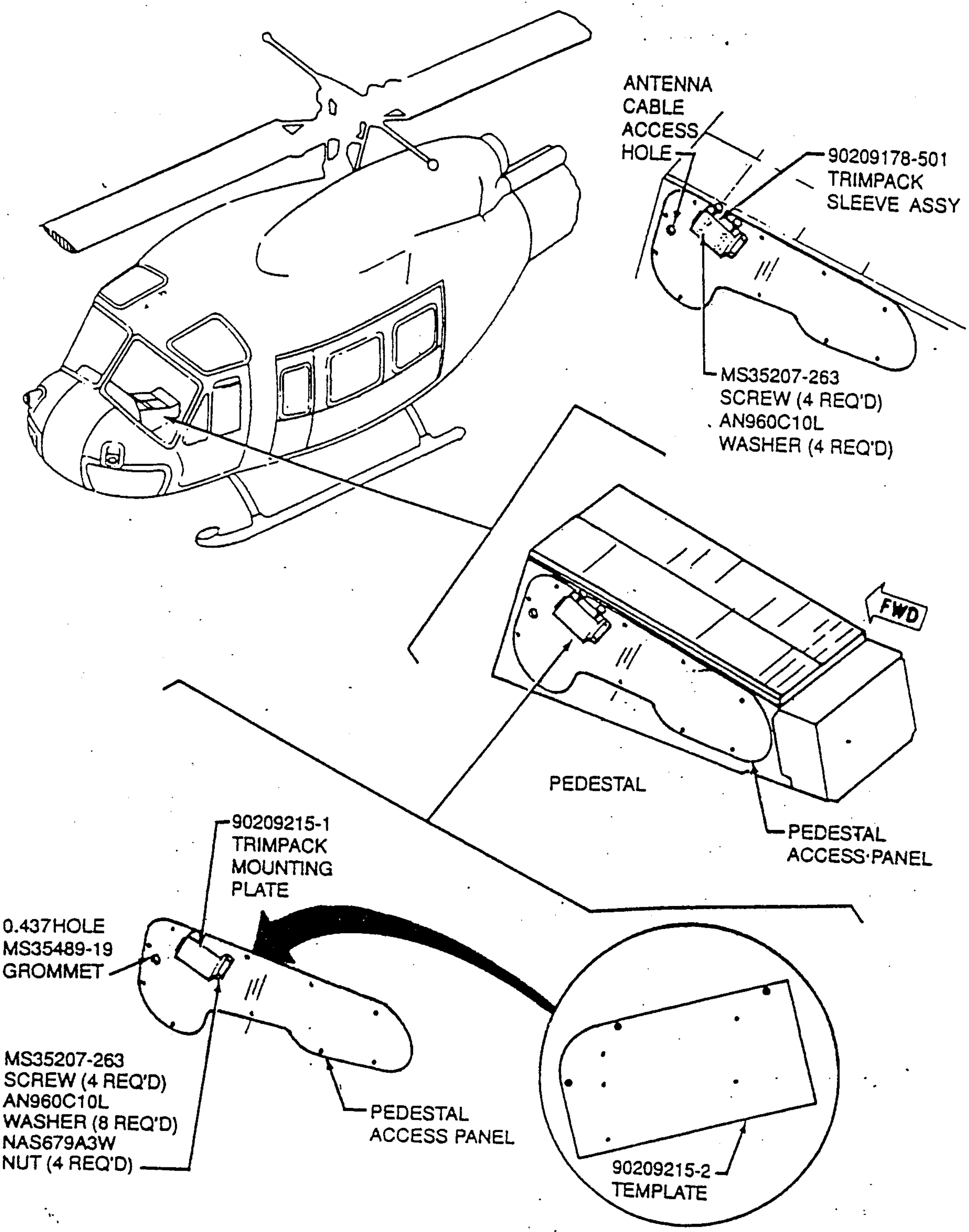
An area for further research may be to evaluate the efficiency in getting completed GPS installation kits from CONUS depots to the user units. This systems engineering effort is not of much value if the end product cannot be moved quickly overseas and then sorted and distributed to the units that have the requirement for installed airborne GPS receivers. The fact that 80 of the 425 UH/1 GPS installation kits shipped overseas were still available after the war (Table 2) may mean the requiring units never received them.

APPENDIX A
GPS ANTENNA MOUNT INSTALLATION
SOURCE: NAVIGATION DIVISION C2SID

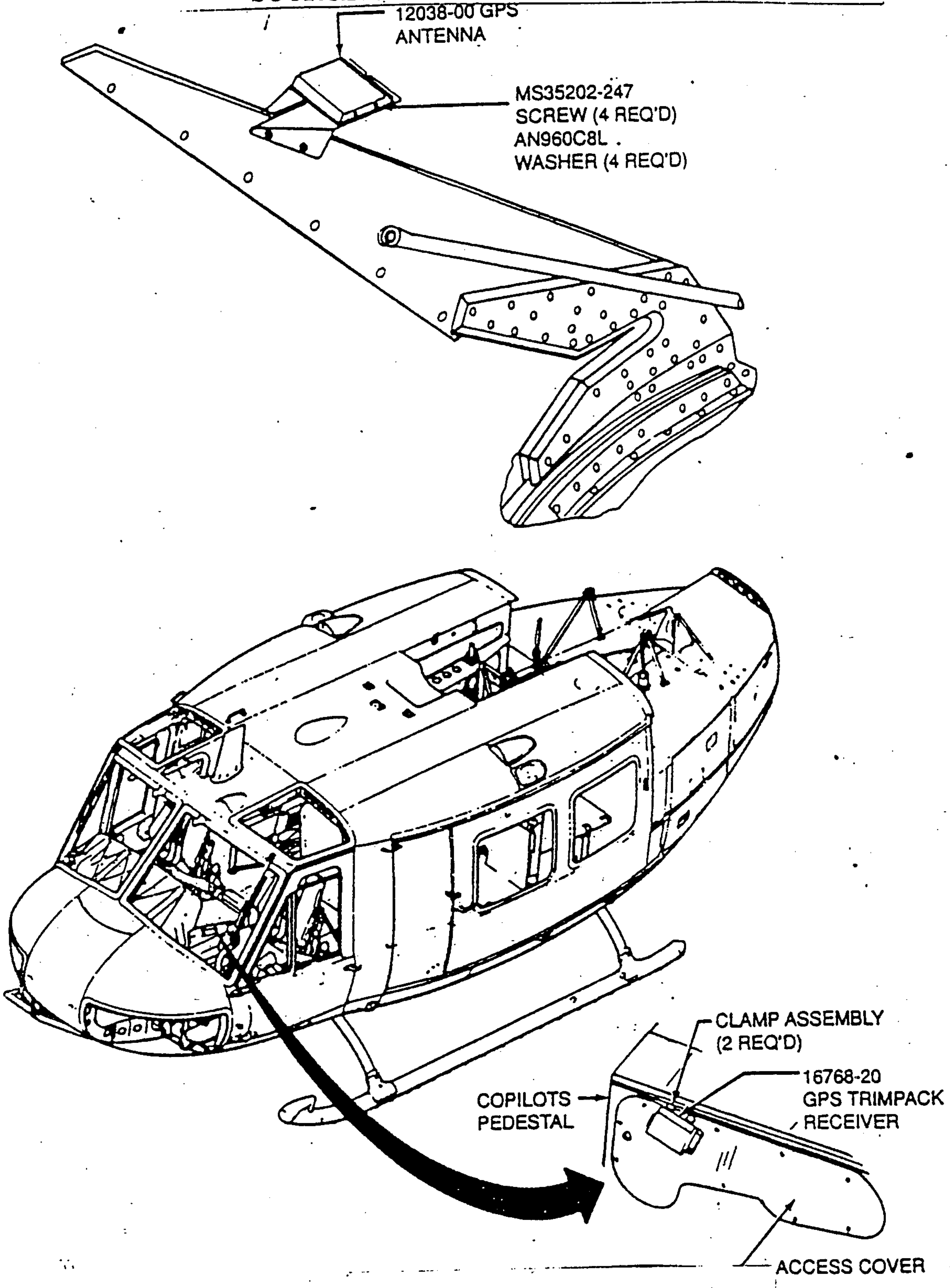


11

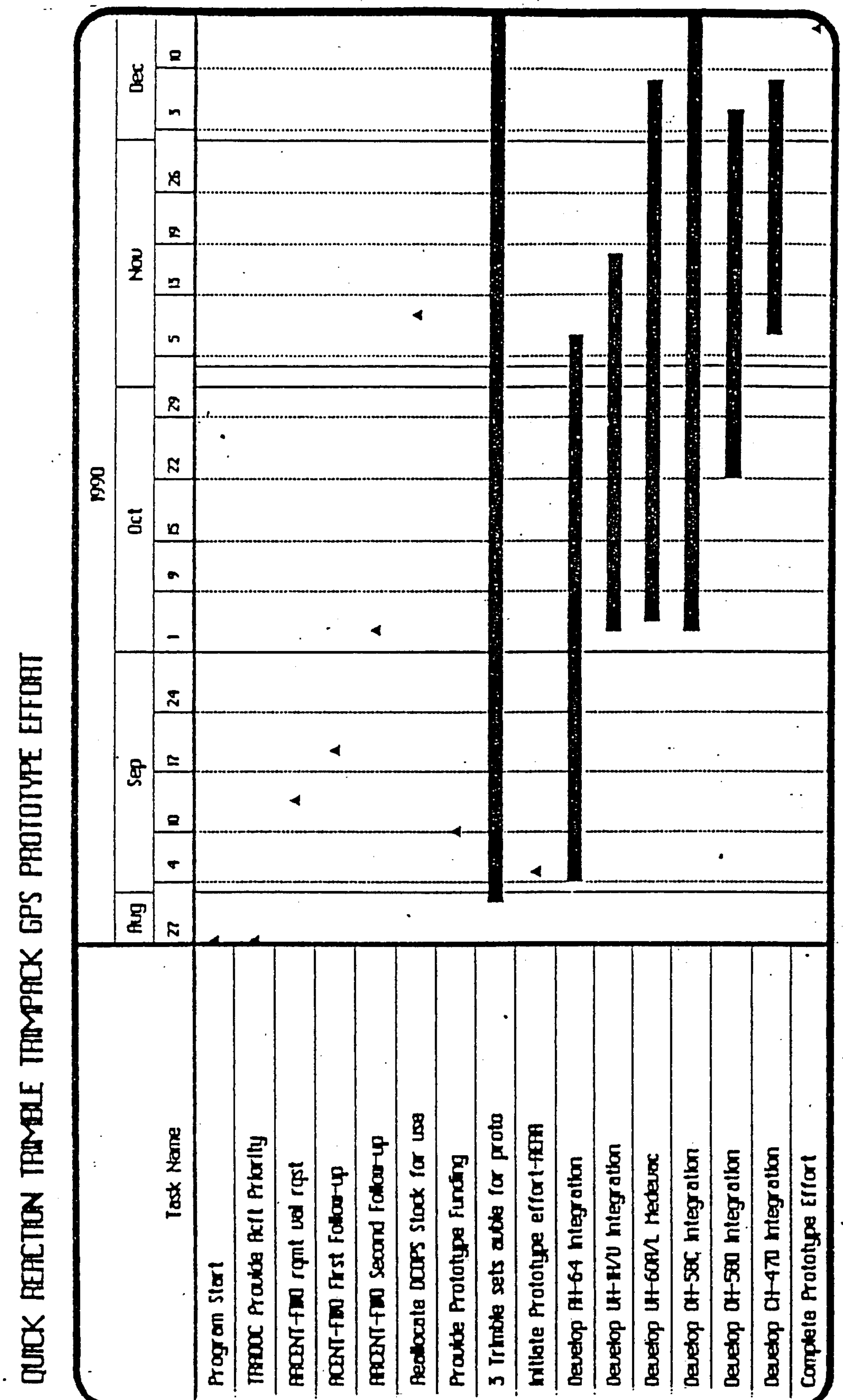
APPENDIX B
TRIMPACK MOUNT AND SLEEVE ASSEMBLY INSTALLATION
SOURCE: NAVIGATION DIVISION C2SID



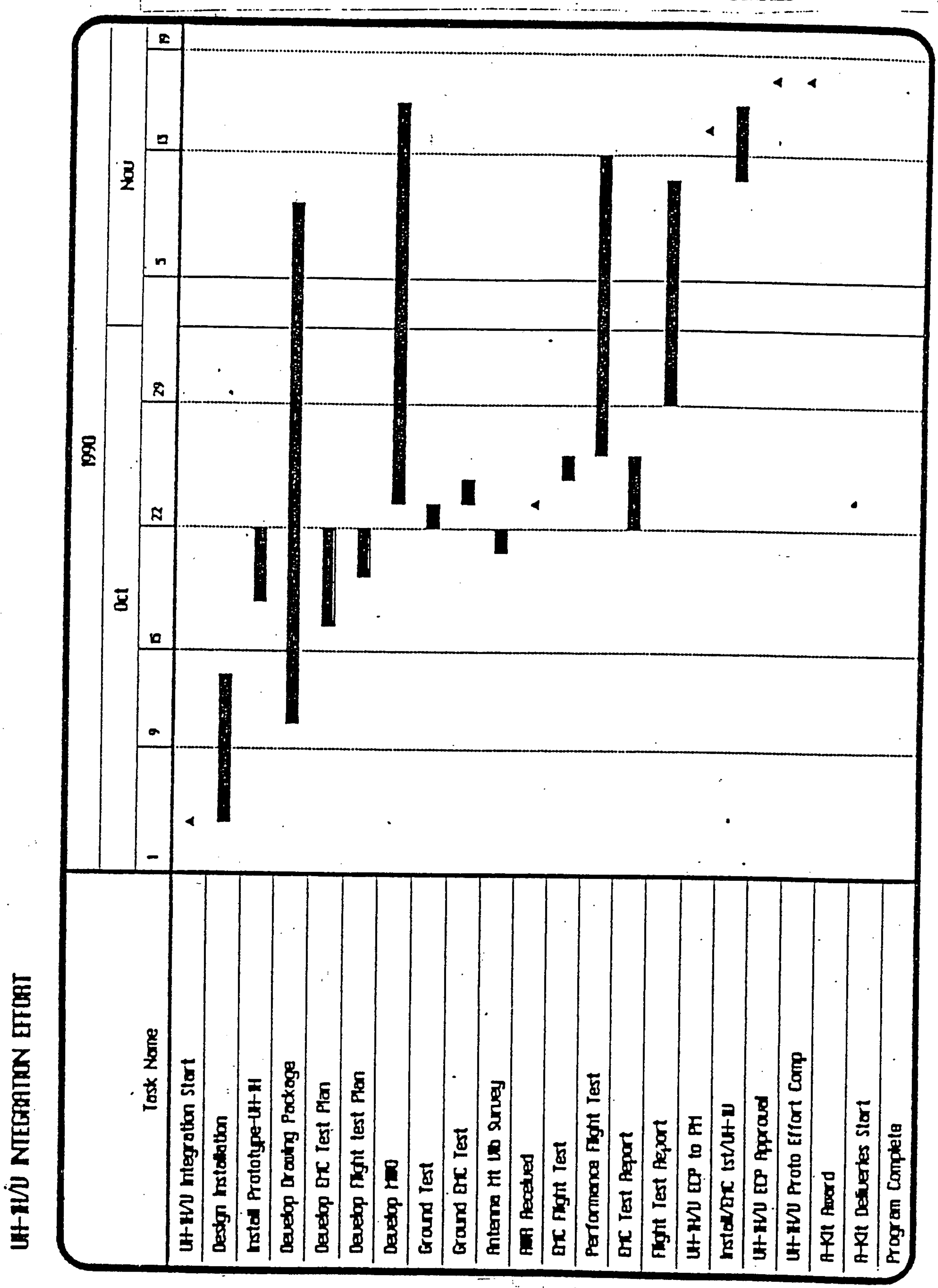
APPENDIX C
GPS ANTENNA AND TRIMPACK RECEIVER INSTALLATION
SOURCE: NAVIGATION DIVISION C2SID



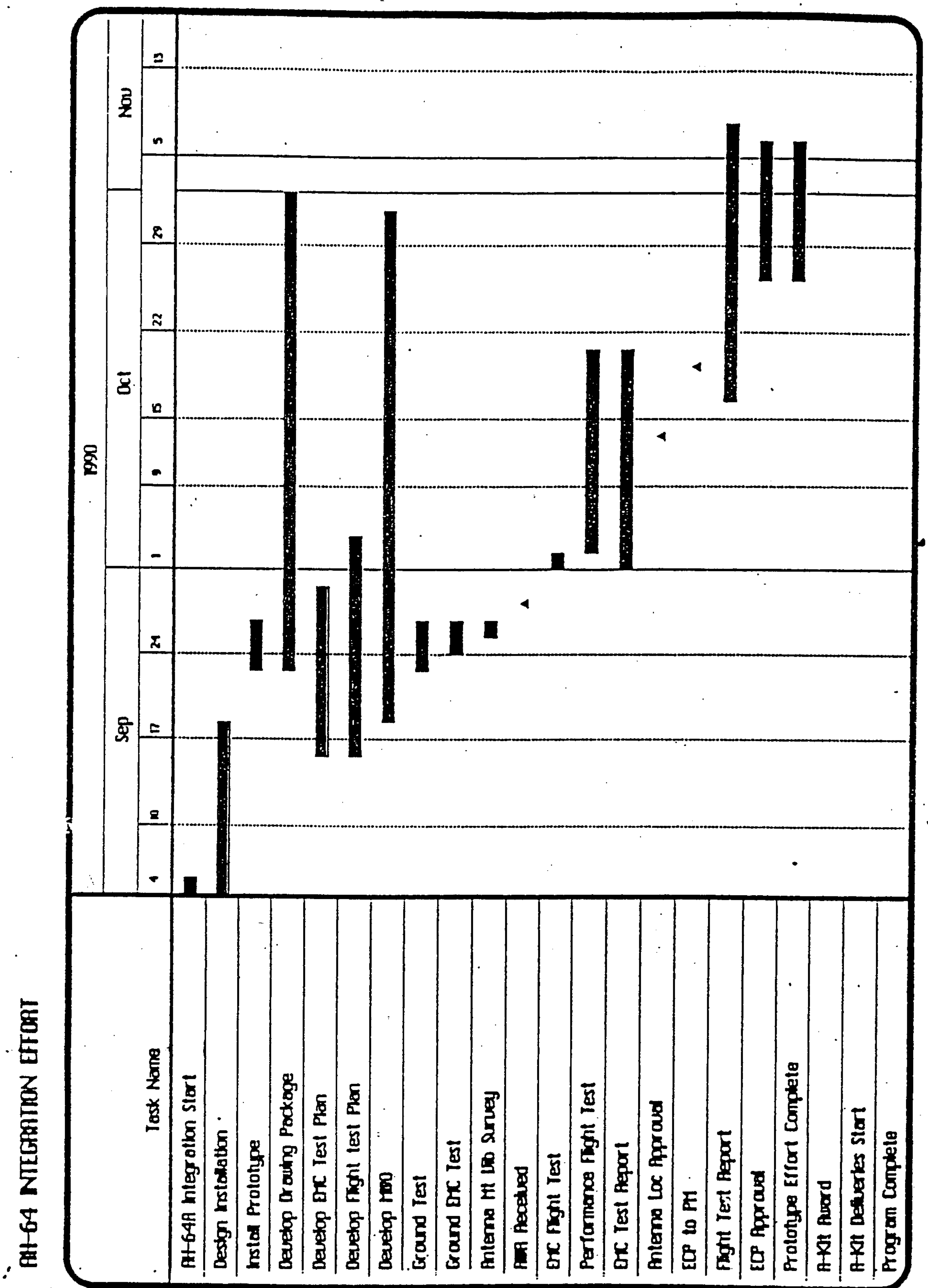
APPENDIX D
QUICK REACTION GPS INSTALLATION PROTOTYPE SCHEDULE
SOURCE: NAVIGATION DIVISION C2SID



APPENDIX E
UH-1H/V INSTALLATION KIT CRITICAL EVENT SCHEDULE
SOURCE: NAVIGATION DIVISION C2SID



APPENDIX F
AH-64 INSTALLATION KIT CRITICAL EVENT SCHEDULE
SOURCE: NAVIGATION DIVISION C2SID



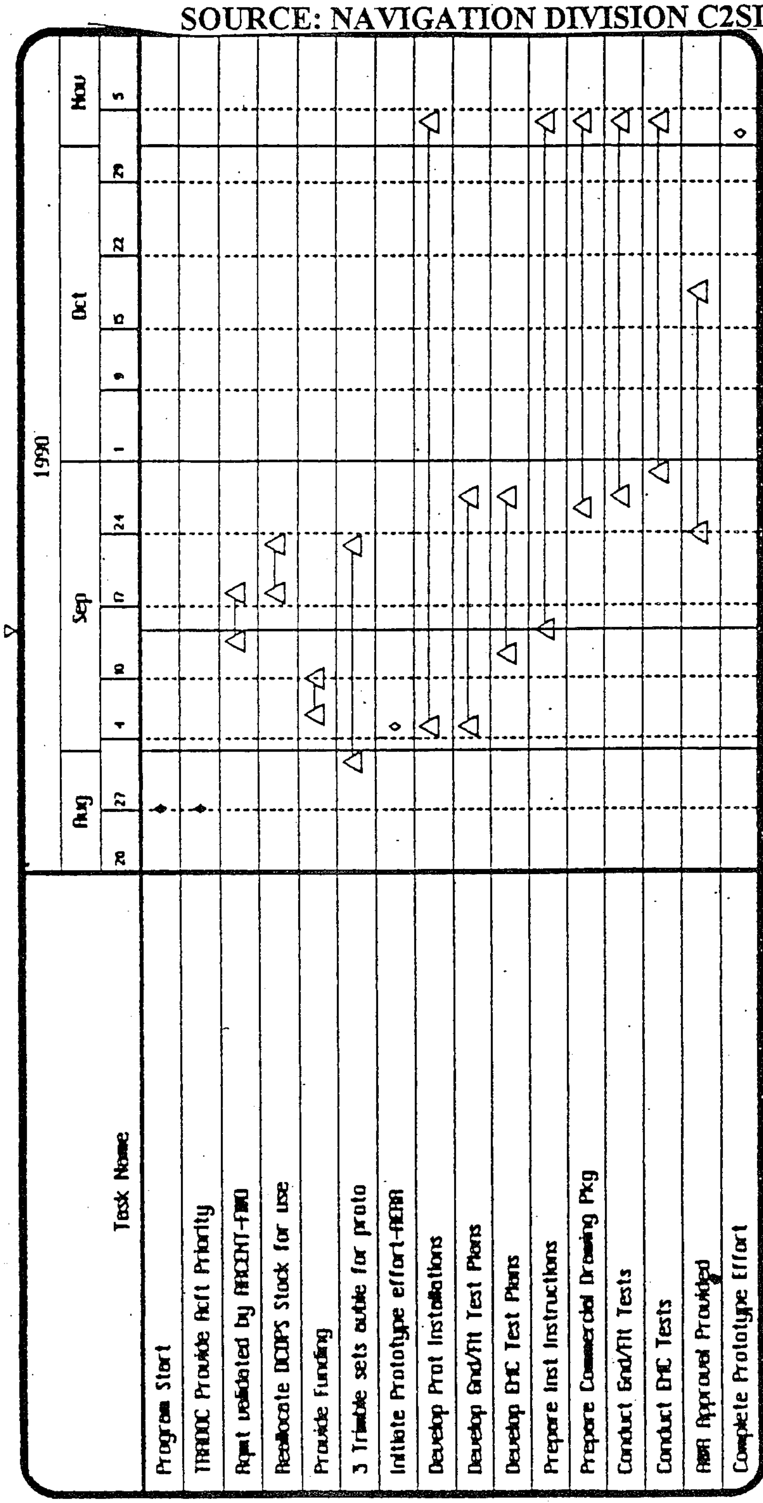
APPENDIX G
QRAG TEAM- KEY PERSONNEL/RESPONSIBILITY MATRIX
SOURCE: NAVIGATION DIVISION C2SID

Quick Reaction GPS Points of Contact

Installation (AVRADA)				Engineering AWR (AVSCOM)	Directorate of Maintenance (AVSCOM)	Black Box (AVRADA)	PM/PEO	USER/DCD (Ft Rucker)	EOC
I	AERA	IE	ILS						
Arlie Keister DSN-995-2040	Jeff Dworkin DSN 624-2119	P. Nyquist DSN 995-3542	V. Mentel DSN 995-4175	J. Walkenhorst DSN 693-1059	Brent Bingham DSN 693-2143	C. Lucas DSN 995-3976	R. Hutson DSN 693-1952	Kelley Stanley DSN 558-3973/4872	Col Ivey DSN 693-1847
Burke DSN 995-2023	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Don Watkins DSN 693-1639		C. Lucas DSN 995-3976	Garrison DSN 693-1418	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Ilaria DSN 995-2619	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Bob Tansey DSN 693-1687		C. Lucas DSN 995-3976	O'Keefe DSN 693-3210	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Burke DSN 995-2023	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Forrest Helzer DSN 693-1683		C. Lucas DSN 995-3976	Wilkens DSN 693-3751	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Gildea DSN 995-3577	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Kirk Pinson DSN 693-1672		C. Lucas DSN 995-3976	Jim Boen DSN 693-1599	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Alexander DSN 995-0201	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Kirk Pinson DSN 693-1672		C. Lucas DSN 995-3976	MAJ Duckworth DSN 693-1371	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Gildea DSN 995-3577	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Denise Boucher DSN 693-1659		C. Lucas DSN 995-3976	Eickhorst DSN 693-1575	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211
Post/Gunsaulis AV 995-2706/0246	Jeff Dworkin DSN 624-2119	Nyquist DSN 995-3542	V. Mentel DSN 995-4175	Bill Lake DSN 693-1679		Lucas DSN 995-3976	John O'Hara DSN 693-1929	Kelley Stanley DSN 558-3973/4872	COL Ivey DSN 693-1211

APPENDIX H
PROTOTYPE INSTALLATION-KIT CRITICAL EVENT SCHEDULE
SOURCE: NAVIGATION DIVISION C2SID

Quick Reaction Trimble Trimpack GPS Installation



APPENDIX I
GPS INSTALLATION KIT- PRODUCTION SCHEDULE
SOURCE: NAVIGATION DIVISION C2SID

SAVAA-I

12 FEB 1991

Trimble GPS Installation Kit Production Status

Aircraft	DEPOT/ Contractor	Kit Quantity	Delivery Schedule (1991) January 4	January 11	January 18	January 25	February 1	February 8	February 15	February 23	March 1	March 8	March 15	March 22	March 29	April 5	April 12	April 19	April 26	Total
UH-1H/V	AERA (DOSS)	425				200		100	125											425
UH-60A/L(& MED) EH-60A	TOAD	450							100	100	100	100	50							450
AH-64A	CCAD	280											100			180				280
OH-58C	TOAD	300										100	100	100						300
OH-58A	AERA/TOAD	50									50									50
CH-47D	AERA/TOAD	175											100		75					175
AH-1F	AERA/TOAD	140												100				40		140
OH-58D	AERA/TOAD	102											102							102
TOTAL	N/A	1922				200		100	225	100	150	200	452	200	75	180		40		1922

Shading Indicates Shipped

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